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technology review

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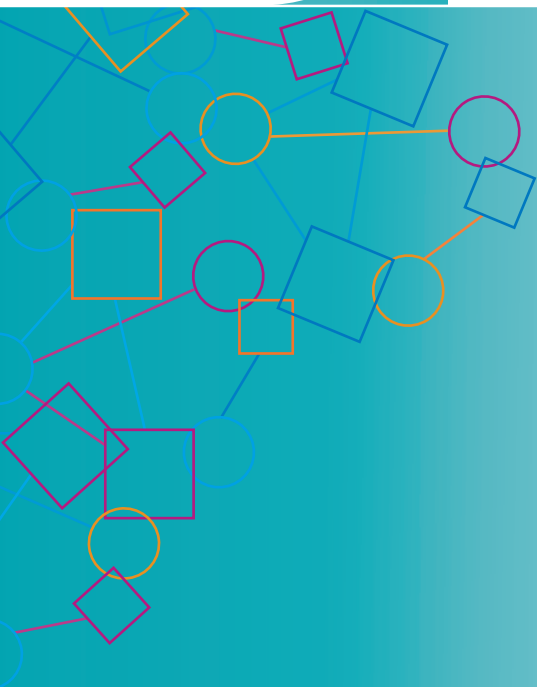
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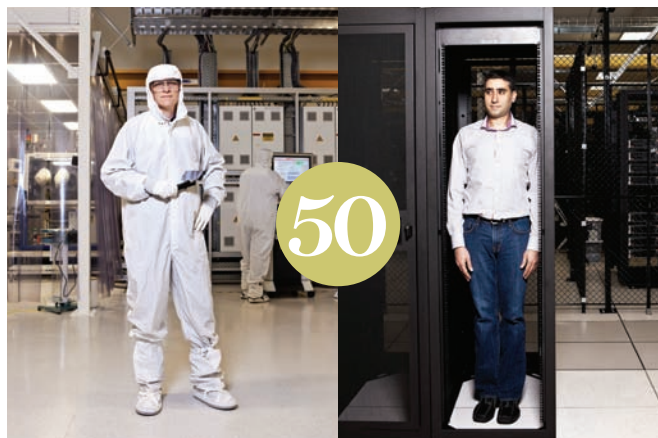


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Drew Houston, CEO of Dropbox
Photo: Winni Wintermeyer



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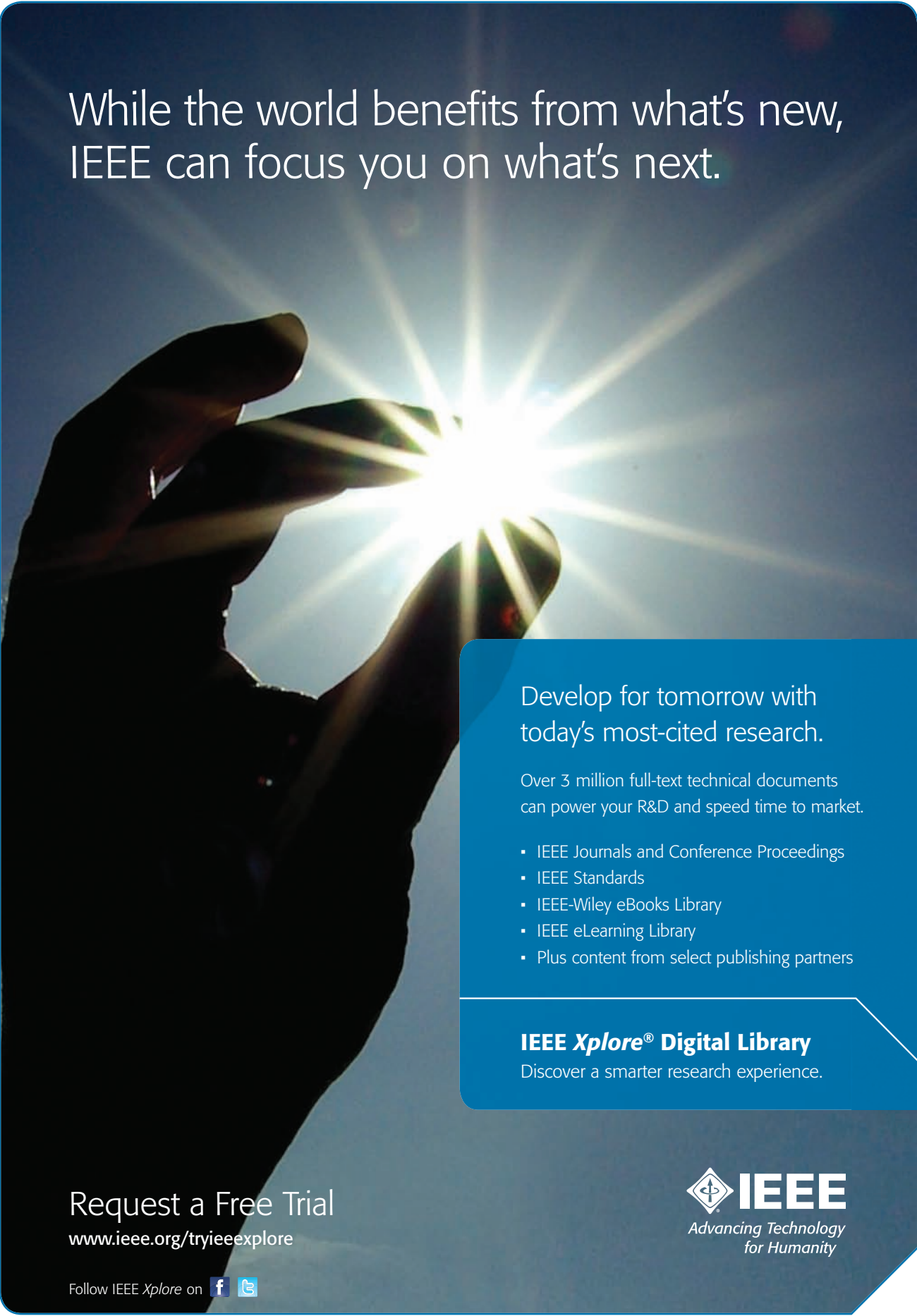
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“Can We Manufacture Tomorrow’s Breakthroughs?” January/February 2012

“One reason for the decline of American manufacturing is the ignorance and apathy of Americans who know the price of a thing but not its value.”

James Eubanks, Trenton, North Carolina

MAKE OR BREAK In the lead story of our January/February package on advanced manufacturing (“Can We Manufacture Tomorrow’s Breakthroughs?”), *TR*’s editor, David Rotman, suggested that America’s diminished role in manufacturing was bad news for innovation everywhere. The article had readers scrambling to prescribe remedies—and lay the blame.

James Eubanks of Trenton, North Carolina, said one culprit was the American expectation of easy access to cheap goods: “One big reason for the decline of American manufacturing is the ignorance and apathy of bargain-loving Americans who know the price of a given thing but not necessarily its value. As long as they can get that \$20 DVD player from Walmart, they couldn’t care less where it was made or how many Americans were put out of a job. Proponents of American manufacturing aren’t just right-wing flag wavers making noise about a nostalgic return to the glory days—they’re acknowledging the fundamental role that a strong manufacturing infrastructure plays in the long-term stability of our nation.”

In an online comment, **kbillet** suggested that the problem was simply corporate greed.

“Senior management only understands part of the picture: dollars. They manage risk, and no risk is always better than even a little risk. And new designs and processes always involve risk. It’s easier to sit on your hands, where you are not personally put at risk of failure. The stockholders enforce this behavior with their profits-now mentality.”

Greed has nothing to do with it, responded **R. Sweeney**. It’s just that U.S. managers tend to have a financial background rather than a scientific or creative one. “In China, companies are organized and led by creative engineers and scientists. In the U.S., even companies started by technical people are quickly dominated by finance and law department types. And

these people have zero understanding of manufacturing—which in their minds is merely a cost to be contained.”

JOB QUAKE In “Tectonic Shifts in Employment,” *TR* chief correspondent David Talbot investigated the damaging effects of automation and technology on the job market. **MiceC540**, in an online post, felt he’d missed a crucial piece of the puzzle. “Technology might be one force behind the tectonic employment shift leading us to a workerless

society, but the outsourcing/offshoring of middle-class jobs is probably an even larger force. We’ve become a society that depends on millions of low-wage workers who are invisibly scattered around the world, and that is the real tectonic force behind the shift occurring in the U.S. job market.”

ZUCKERBERG’S LAW Will our capacity to share on Facebook ever reach its limit? Or are we doomed to share ever larger chunks of our lives in a nightmare social-media version of Moore’s Law? Paul Boutin explored that question in his review “The Law of Online Sharing.” In an online comment, **zrzz** responded: “I have yet to see anything profound or life-changing expressed on Facebook. It’s the lunchroom of the Internet. Just a bunch of people engaging in inane small talk. We have more information than we ever had before, but it’s all fluff.”

Sophie S retorted: “Sometimes when we pick apart the fluff we find grains of truth.”

“I used to be one of the biggest Facebook haters around,” wrote **getsocial101**. “Now I see the power of it and actually enjoy being on it. From the perspective of small local businesses, it’s a great way to attract new customers. And it’s free.”

EYE IN THE SKY And finally, our Hack on a camera-laden ball that takes a panoramic photo if you throw it in the air (“Eye Ball”) captured the imagination of several posters. “Would be very cool for sports,” wrote **libchick26**. “Viewers could get a whole new perspective of the game.” **Erbium** had other ideas: “I could use this in the center of an apartment courtyard. Throw it up in the air and see all the junk people store on their porches hidden behind the railing.” **tr**

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INNOVATION

Be the Change

Great technology companies often begin when ambitious people create change they want to see, says David Lee.

One of my favorite quotes is from Mahatma Gandhi, who advised us to “be the change you want to see in the world.” I have often been reminded of it as an early-stage investor in startup companies at SV Angel, where I meet hundreds of founders chasing extraordinary dreams and visions. These people aren’t starting innovative companies because it’s the fashionable thing to do; they’re starting companies because it’s the best way to effect the change they are seeking (*see the TR50*, p. 36).

Late last October, I heard Mark Zuckerberg talk at Startup School 2011 about why he started Facebook. His message was that he didn’t set out to start a company for the sake of it. He reminisced about how back in 2004, over pizza, he and his friends dreamed of the next great software platform and how it would inevitably involve

social participation. He ultimately created an innovative product and company because it was the fastest way for him to prompt the change he wanted to see in the world. Today Zuckerberg and Facebook have created a software platform for the ages. It is an engineering marvel that serves nearly a billion people, supports thousands of developers, and has created billion-dollar industries giving people new ways to consume, share, and create media.

Three days after I heard Zuckerberg speak, Jack Dorsey, a founder of Twitter and Square, talked about the same topic at an SV Angel summit for founders. Dorsey’s advice on building a company echoed Zuckerberg’s description of starting one. Building a business, Dorsey said, is a way of “thinking about the idea that you want to see in the world.” The company is the structure that lets the idea flourish: you need it in order to hire people to build the product, to get money from investors to hire the people, and ultimately to generate profits so you don’t need money from investors. Money is just oxygen for the idea. The companies Dorsey has started are two of the most interesting of the past decade: Twitter has redefined the way content is distributed and consumed, while Square is on its way to enabling everybody on the planet to accept credit-card payments.

Zuckerberg and Dorsey are clearly outliers. But they are just two examples of founders who “scratched their own itch” or personify the products and companies they have created. Many of the great innovations that we have seen in the software and Internet industries start with similarly modest beginnings—a talented engineer or coder trying to solve a troubling or perplexing problem. Usually these problems are technically complex and challenging—that is part of the appeal. Usually—but not always—they lead to big market opportunities and technical breakthroughs.

DAVID LEE IS FOUNDING MANAGING PARTNER AT SV ANGEL, WHICH HAS INVESTED IN MANY COMPANIES, INCLUDING TWITTER AND SQUARE.

MEDICINE

Healthy Skepticism

Medical technologies are too rarely evaluated with scientific rigor, says Harlan Krumholz.

We can become so enamored of new technology in medicine that we sometimes forget it needs to be tested to prove it can accomplish what it seems to promise.

Recently, for example, many health-care systems have embraced a range of remote telemonitoring products to track the health of patients at home. Some patients use such monitoring apps and gadgets on their own initiative (*see “The Patient of the Future,” p. 60*). It seems logical that more data for doctors and patients is a good thing. In medicine, however, what matters is whether the innovation helps people live longer, with better health and quality of life. We have not yet assessed whether health-tracking apps actually do this.

In reality, few new technologies are subjected to rigorous evaluation. Unlike new drugs, most can legally be put into practice without formal testing. Moreover, the testing that is done is often carried out by the people who developed the technology, so study designs are susceptible to subtle and often unintended bias.

With colleagues, I recently published the results of a large NIH-funded randomized trial of a highly touted telemonitoring system for patients with heart failure. Patients called an automated phone system every day to answer a series of questions about their symptoms. Certain responses triggered alerts to doctors. It seemed like a simple, effective technology destined to transform medicine and was promoted to hospitals as highly effective. Unfortunately, our study failed to find any benefit. These results were confirmed within months by another large independent evaluation of a similar product.

NICK REDDYHOFF



The lesson: we cannot assume on the basis of mere common sense that a promising technology will work. We need to have our assumptions confirmed by independent studies. This principle applies to a host of medical technologies, including other self-monitoring and reporting tools and electronic health records.

There are many reasons why a technology might not realize its promise. The trickiest have to do with implementation: even a technology that works perfectly and is capable of great things may be used in a way that makes for little or no impact on patients.

Medical technologies are not as simple as pills that a patient takes or does not take. Existing practices may not be able to accommodate a novel approach. Information generated by monitoring systems may be misused, misunderstood, or ignored. For whatever reason, “can’t miss” technologies often do.

Developers of new technologies need to prototype and test with those complexities in mind. At the same time, independent tests of medical technologies need to become faster, cheaper, and more routine. Ultimately, the promotion and implementation of technologies like home monitoring must be based on the results that matter most: the extent to which we have made the patient feel better and live longer.

HARLAN KRUMHOLZ IS THE HAROLD H. HINES JR. PROFESSOR OF MEDICINE, EPIDEMIOLOGY, AND PUBLIC HEALTH AT THE YALE UNIVERSITY SCHOOL OF MEDICINE.

AFRICA

Frustrated Innovation

Africa’s technology community will thrive only by facing up to the continent’s fundamental problems, says Ory Okolloh.

Africa is trending, if stories in the international media over the last year are anything to go by. And no story about “rising Africa”—many of us would argue it has “arisen”—is complete without mention of the role technology is playing in this transformation.

The rise of the mobile phone, disruptive SMS services like the money-transfer platform M-Pesa, and mobile tools for democracy like Ushahidi have been the subjects of numerous reports. Unfortunately, these good-news stories haven’t been accompanied by a more nuanced view of the opportunities being created and where they may take us (*see “Kenya’s Mobile Prescription,” p. 52*).

Technology is the perfect refuge for African capability stifled elsewhere by badly run governments and years of misplaced foreign aid. Ubiquitous connectivity in a world without legacy infrastructure, together with the potential to learn coding or anything else online, has allowed technology entrepreneurship to flourish. The barriers to entry have been dramatically lowered. Startup incubators and app competitions are springing up throughout the region. However, there is a risk that the buzz, so good at attracting international attention, will remain only that.

If local technology startup companies are really to thrive and become sizable businesses, other areas need to experience their own versions of the technology sector’s burst of energy and freedom. Entrepreneurs today face challenges such as a nonexistent IP regime, poor infrastructure, high penalties for failure, and oppressive bureaucracy and

shortsightedness, all of which stand between businesspeople and the huge market of a billion people that Africa represents. A scenario I come across far too often is that a young African technologist with a great product for industry X, company Y, or government department Z gets a chance to demonstrate it, to wide acclaim. But to translate it into an actual business opportunity, the innovator is expected to hand over cash or a 40 percent stake in the business, to smooth things out with the “head of IT procurement.”

Too few entrepreneurs have managed to overcome these obstacles. Frankly, we need to spend more time learning from the



successes of little-heralded businesses like Seven Seas Technology, an IT services company in Kenya, and MoTribe, which helps brands build their own mobile social networks in South Africa. Both of these have managed to become large and profitable companies, a goal that generally eludes those caught up in the African “tech is the promised land” bubble.

As I see it, tech in Africa 1.0 was the mobile-phone boom, and version 2.0 was about new apps developed in response to local needs. Tech in Africa 3.0 should be about those who are successful in transforming the chatter into real opportunities. **tr**

ORY OKOLLOH WAS A COFOUNDER OF USHAHIDI, WHICH OFFERS AN OPEN-SOURCE CRISIS-MAPPING TOOL. SHE TWEETS AS KENYANPUNDIT AND IS GOOGLE’S HEAD OF POLICY FOR AFRICA. SHE WRITES HERE IN A PERSONAL CAPACITY.



Radically Better

What the TR50 companies have in common.

Every year, *Technology Review* declares 50 companies the most innovative in the world: the TR50.

On page 36, special projects editor Stephen Cass, who manages the selection process, nicely describes our criteria for choosing the companies: “What is a TR50 company? It is a business whose innovations force other businesses to alter their strategic course.” The companies we like, he writes, “have demonstrated original and valuable technology, are bringing that technology to market at a significant scale, and are clearly influencing their competitors.”

Put another way: the necessary condition for a company’s election to the TR50 is the successful commercialization of a new technology. In this issue, we celebrate the startups and public companies marketing innovative technologies. They’re creating entirely new businesses or disrupting existing industries.

As I have written in this space on an earlier occasion, “Innovation is not invention, still less is it scientific discovery” (see “*The Geography of Innovation*,” *January/February 2008*). An innovation, I asserted, must be valuable—which is to say, it is something that people can buy, or that exists in a more generalized social context of supply and demand. Genuinely innovative technologies allow individuals or organizations to do valuable things they could not do heretofore, or they reduce the costs and difficulties of doing something already valued.

How disruptive are the innovations of this year’s TR50? In most cases, very.

In “The New Net,” on page 40, one of our information technology editors, Tom Simonite, explains how the startup Nicira is reinventing computer networking. Nicira’s software—ponderously named “Network Virtualization Platform”—creates a programmable software replica of a network’s routers and switches. Simonite writes, “It should trigger a new wave of Internet innovation in everything from mobile apps to online banking security.” Nicira’s product could make the Internet’s cloud services so reliable and secure that large companies will use them as readily as small businesses do today. More futuristically, it would let telecommunications companies smoothly transfer data centers from place to place, to the safest location or to wherever power and cooling were cheapest. As with all real innovations, there may be losers: “Cisco and other vendors of traditional networking equipment will need to adapt, fast.”

Alta Devices, another TR50 startup, has discovered how to cheaply manufacture solar cells made from gallium arsenide. The material is tremendously attractive for photovoltaics, writes David Rotman, *Technology Review*’s editor. “Not only does it absorb far more sunlight than silicon—thin films of it capture as many photons as silicon 100 times thicker—but it’s less sensitive to heat than silicon solar cells, whose performance dramatically declines above 25 °C.” The main problem with gallium arsenide has been its high cost. But Alta knows how to make extremely thin, rugged layers of the material. This might realize the hopes of the most ardent promoters of solar technology. The gallium arsenide technology could produce energy at seven cents per kilowatt-hour, writes Rotman: “At such a price, solar would be competitive with fossil fuels, including natural gas.” That’s a disruptive innovation.

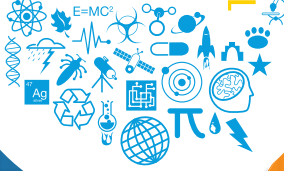
We chose the startup Dropbox as our exemplary TR50 company, asking its chief executive and cofounder, Drew Houston, to grace the magazine’s cover. Dropbox, we write, “lets people use almost any computing device to store files in folders in the cloud as thoughtlessly as they store files in folders in their device’s memory” (see *Q&A*, p. 24). Achieving that simplicity of use forced the company to wrestle with numerous operating systems, four Internet browsers, and any number of file systems. But it also won a devoted following of more than 50 million users around the world, disrupting a marketplace of around 15 Internet file-sharing companies, including Apple’s iCloud. When I asked Houston how Dropbox’s simplicity was achieved, he answered: “We want you to have your stuff with you wherever you are, and that requires that we remove anything that gets in the way. There are technical hurdles that we’ve had to overcome to provide the illusion that everything is in one place.” One must use Dropbox to fully grasp how disorienting is its innovation: the edges between one’s device and the Internet blur and disappear.

What Nicira, Alta Devices, Dropbox, and all the TR50 companies have in common is an impatience with existing technologies and a confidence that radically better technologies could win customers away from even the largest, most established competitors, improving people’s lives in myriad and interesting ways. But write to jason.pontin@technologyreview.com and tell me what you think of our choices for this year’s TR50.

—Jason Pontin

MARK OSTOW

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The Planetary Society
Washington Family Magazine
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You Can Do the Rubik's Cube
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to market



BIOMEDICINE

Cheap Genes

A NEW BENCHTOP DNA sequencer will allow medical clinics to sequence a patient's entire genome in a day. The system uses this disposable semiconductor chip, which has an array of microscopic wells containing known DNA templates on its upper surface. Fragments of a patient's genome are washed over these wells, and matches between a template and the patient's DNA trigger electronic sensors attached to the well. The chip and required reagents together cost \$1,000 per genome. The sequencer will allow doctors, as part of a patient's normal care, to test for genetic conditions or assess whether the patient is likely to respond to a particular drug.

■ **Product:** Ion Proton Sequencer **Cost:** \$149,000 **Availability:** Mid-2012 **Source:** www.lifetechnologies.com
Company: Life Technologies



ENERGY

Stretching a Gallon for 100 Miles

FORD'S PLUG-IN HYBRID is said to be the most fuel-efficient midsize car in the world, capable of getting the equivalent of over 100 miles per gallon. The car can be charged at either a 120-volt outlet or a 240-volt outlet equipped for supplying electric vehicles, and its charging schedule can be programmed using a smartphone monitoring app.

■ **Product:** Fusion Energi **Cost:** N/A **Availability:** Fall 2012
Source: www.ford.com **Company:** Ford



COMMUNICATIONS

Plug-In Intelligence

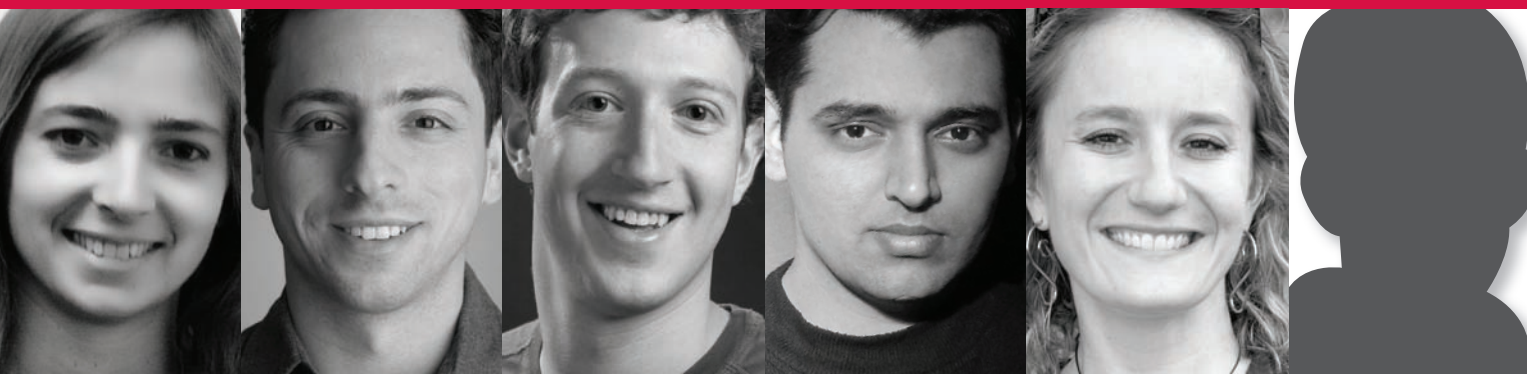
A SET-TOP BOX compressed into a device the size of a USB flash drive, the Streaming Stick plugs into a TV's HDMI port and requires no external power source. Using a built-in Wi-Fi radio, it converts any set into an Internet-enabled smart TV, allowing viewers to stream video from online services such as Netflix and Hulu. Thanks to the HDMI connection, users can control the Streaming Stick with the same remote that they use for the TV.

■ **Product:** Roku Streaming Stick **Cost:** N/A **Availability:** Mid-2012 **Source:** www.roku.com
Company: Roku

FORD (CAR); ROKU (TV ADAPTER)



Do You Know an Outstanding Young Innovator?



Helen Greiner
IS Robotics
TR100 1999

Sergey Brin
Google
TR100 2002

Mark Zuckerberg
Facebook
TR35 2007

Pranav Mistry
MIT
TR35 2009

Danah Boyd
Microsoft Research
TR35 2010

Who is Next?
TR35 2012

Since 1999, the editors of Technology Review have honored the young innovators whose inventions and research we find most exciting; today that collection is the TR35, a list of technologists and scientists under the age of 35. Their work—spanning medicine, computing, communications, electronics, nanotechnology, and more—is changing our world.

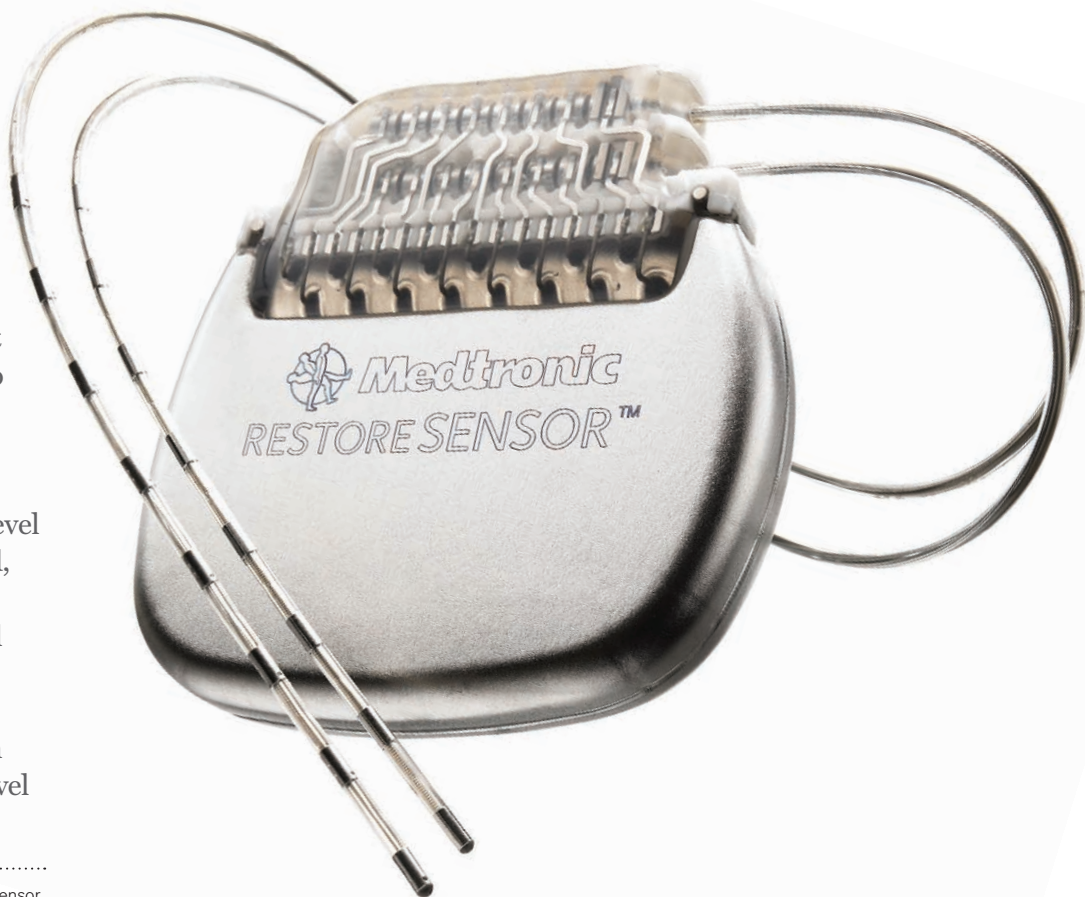
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NOMINATIONS CLOSE MARCH 31, 2012

BIOMEDICINE

Automatic Relief

SOME PATIENTS suffering from chronic pain receive an implant that sends an electrical signal to the spine, blocking pain signals before they reach the brain. As patients move between sitting, standing, and lying down, the level of stimulation must be adjusted, which until now they have had to do manually with an external programmer. Medtronic's new implantable stimulator incorporates accelerometers that can detect motion and adjust the level of stimulation automatically.



■ **Product:** Medtronic AdaptiveStim with RestoreSensor
Cost: N/A **Availability:** Now
Source: www.medtronic.com **Company:** Medtronic



COMPUTING

Desktops in the Cloud

PEOPLE WHO use iPads can now get access to a virtual Microsoft Windows desktop, complete with Word, Excel, and PowerPoint applications, using OnLive's video-streaming technology (see "Cloud Streaming," TR10, May/June 2011). Because this technology eliminates the buffering that normally occurs with video-streaming services, applications hosted on OnLive's servers can respond to user input as swiftly as if the applications were running locally on a mobile device. The OnLive desktop comes with two gigabytes of storage.

■ **Product:** OnLive Desktop **Cost:** Free **Availability:** Now
Source: desktop.onlive.com **Company:** OnLive

MEDTRONIC (IMPLANT); ONLIVE (VIRTUAL DESKTOP)



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*Not all features are available for Mac version.

**With purchase

BIOMEDICINE

Performance Monitor

THIS EARPIECE and boom attaches to eyewear and connects wirelessly to sensors using the ANT+ standard, which can measure data such as an athlete's heart rate or the speed of a bicycle. The sensors can deliver information via synthesized speech or a visual signal on the boom, which has a series of seven LEDs that can alert a wearer who is straying out of a desired performance window. Users can cycle between sensors by tapping the earpiece.

■ **Product:** Sportiiiis **Cost:** \$200 **Availability:** Now **Source:** www.4iiii.com **Company:** 4iiii

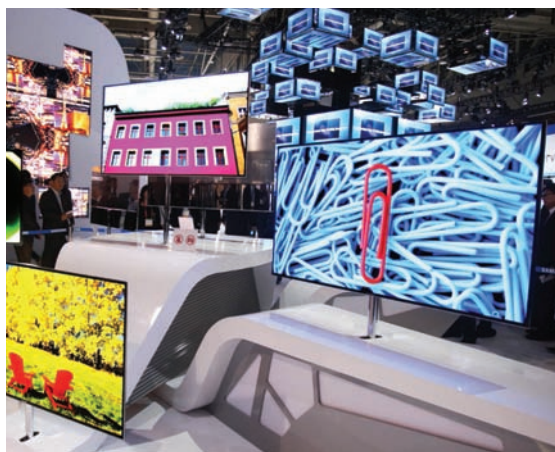


COMMUNICATIONS

Rich Sounds

TINY HOLES ventilate the magnetic assemblies that move the sound-producing diaphragms in these high-fidelity headphones. The ventilation eases airflow that would otherwise cause the diaphragm to wobble slightly, introducing distortions into the sound.

■ **Product:** HD700 Headphones **Cost:** \$1,000 **Availability:** Now **Source:** www.sennheiserusa.com **Company:** Sennheiser



MATERIALS

Organic Television

AT 55 INCHES, the screen size of this TV represents a leap in OLED manufacturing. OLEDs allow bright colors to coexist with dark blacks, providing better picture quality than conventional flat-screen technologies. Viewers can also control smart-TV functions, such as social-media applications, with voice or motion commands.

■ **Product:** Super OLED TV **Cost:** N/A **Availability:** Later in 2012 **Source:** www.samsung.com **Company:** Samsung

WESTINGHOUSE AP1000 RECEIVES Final Design Certification.



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Small Gains

Wind and solar power are ramping up quickly, but the world's demand for electricity is growing much faster.

The use of wind and solar power ballooned almost ninefold from 2000 to 2009, the most recent year for which the International Energy Agency has made data available. But that hasn't really shifted the overall mix of the world's electricity supply.

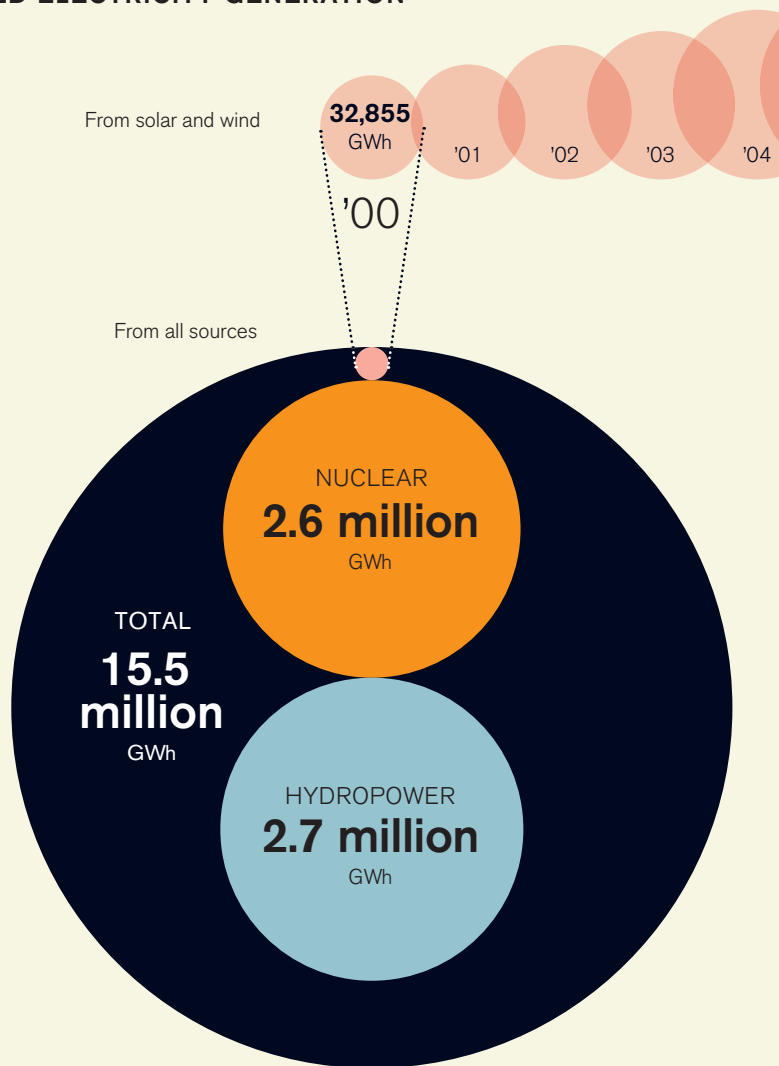
That's because worldwide demand for power is growing on a different scale. From 2000 to 2009, as the annual generation from wind and solar rose by about 260,000 gigawatt-hours (GWh), total generation increased by nearly 4.7 million GWh.

As a result, carbon dioxide emissions from electricity production, which represent roughly 40 percent of the world's energy-related emissions, keep rising. The figure leveled off in 2008 and shrank in 2009 because of the global recession, but an international group of climate scientists recently reported that total fossil-fuel-related emissions grew by 5.9 percent in 2010, the largest annual increase ever recorded. Over half of that growth came from increased combustion of coal, which has held steady as the source of about 40 percent of the world's electricity. Much of the new demand is coming from Asia.

In these charts, we show how the world's sources of electricity changed—and didn't change—in the previous decade. The message: solar and wind have a long way to go.

—Mike Orcutt

TOTAL WORLD ELECTRICITY GENERATION



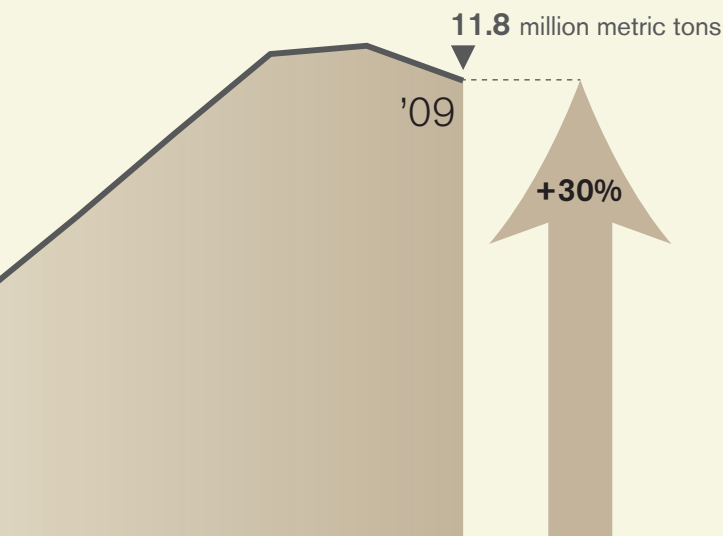
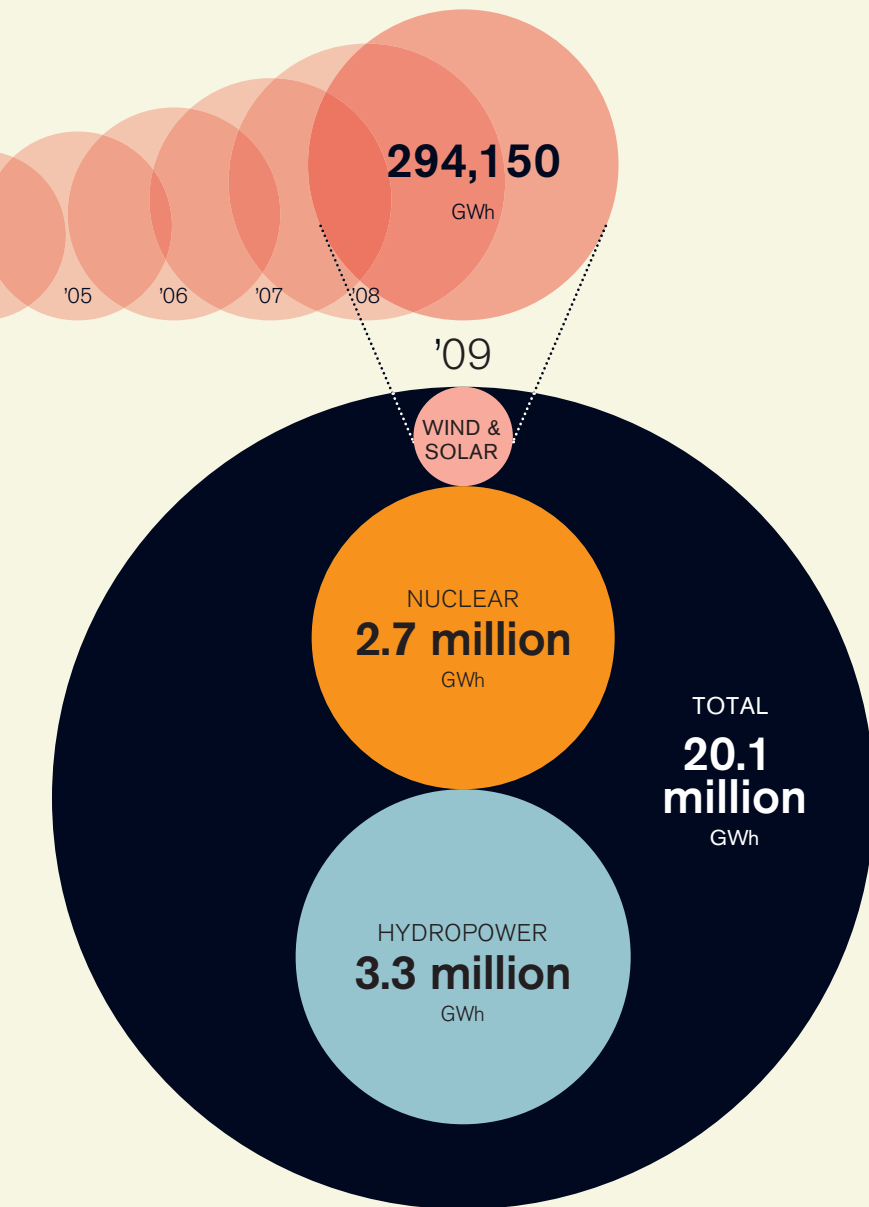
CO₂ EMISSIONS

(from electricity and heat production)

9.1 million metric tons

'00

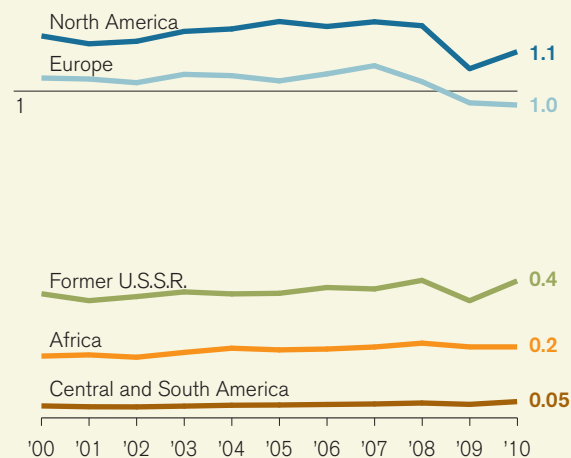
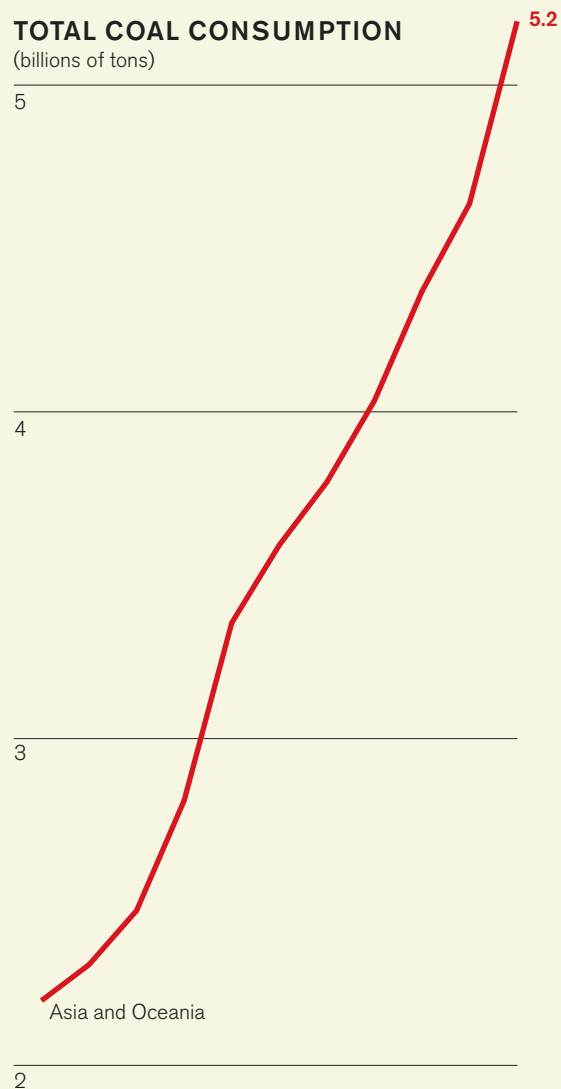
Information graphic by
INFOGRAPHICS.COM
and MIKE ORCUTT



Sources: International Energy Agency
and the U.S. Energy Information Administration

TOTAL COAL CONSUMPTION

(billions of tons)



Q&A

Drew Houston

The CEO of Dropbox explains why simplicity is so hard to achieve.

A bewildering number of services let a computer and smart-phone users store and share files in the Internet's cloud. But one file-hosting service in particular has evoked the kind of devotion ordinarily accorded social-networking services or beloved hardware manufacturers: Dropbox, the product of a startup founded in 2007 by MIT computer science students Drew Houston and Arash Ferdowsi. The service lets people use almost any computing device to store files in folders in the cloud as thoughtlessly as they store files in folders in their device's memory. Achieving that simplicity of use—something Houston calls “an illusion”—is very difficult, because it forces the company to wrestle with all the variants of the major operating systems, four Internet browsers, and any number of network file systems. No other service supports so many different systems. More than 50 million people around the world have been beguiled by Dropbox, which is free to many users. The company's robust growth, together with revenue from the fraction who pay for extra storage and options, has been rewarded by a valuation that various reports place as high as \$4 billion. *Technology Review's* editor in chief, Jason Pontin, spoke to Houston, the chief executive.

TR: Why did you want to start a company in a field—Internet file hosting—where there were so many competitors? I count as many as 15, including Apple's new iCloud service.

Houston: For me, it goes all the way back to MIT, where there is a campus network called Athena. You can sit down at any of thousands of workstations and your whole environment follows you around: not just your files but where your icons were on your desktop. Then I left and discovered that no one had really built that for the rest of the world.

Why was Athena so attractive?

You never had to sprint across campus to pick up some paper. You didn't have to worry about backing anything up, because the whole point was the network was ubiquitous and it was taken care of for you.

It seemed clear to me that in the future [in the wider world] someone was going to take care of this stuff. There were lots of technologies that purported to do so, but when you used them you found they only bit off a little bit of the

problem. You'd install one application to back your stuff up; you'd install another app to sync things between computers—and you'd sign up for a Web service to upload

your files. I just thought: computers can do a better job than people of remembering all these details.

Tell me the requisite founder's tale.

The breaking point for me was a bus ride. I went down to Boston's South Station to ride the Chinatown bus to New York. I was thrilled to open my laptop and have four hours where I could finally get some work done. But I had that sinking feeling that something was wrong, and I started feeling in my back pocket for my thumb drive, and of course I could just see it sitting on my desk at home. So I sulked for about 10 or 15 minutes and then opened up the [text] editor and

wrote some code that I thought would solve the problem. And I met up with Arash through a mutual friend at MIT, and he decided to drop out with a semester left, and we went to California and got to work.

How does the apparent simplicity of Dropbox's user experience emerge from the complexity you must manage?

We want you to have your stuff with you wherever you are, and that requires that we remove anything that gets in the way. There are technical hurdles that we've had to overcome to provide the illusion that everything is in one place, that it just sits there, and that getting it is reliable, fast, and secure.

Achieving that experience is not simple: we have a polished exterior, but there's this jungle of different operating systems [with which we must work] and even gnarlier stuff like operating-system bugs and incompatibilities. It's a hostile environment: we macheted our way through that jungle of problems. It was a bunch of us spending big chunks of our 20s chasing down these obscure compatibility issues.

Can you give me an example?

On the Mac, when you look at the Finder, your Dropbox folder has this little green check on it that indicates that your files are in sync. That little piece of visual feedback was really important to us. And to do that without access to Apple's source code, we had to reverse-engineer how the Finder works and find the little piece of code that draws the icons and perform open-heart surgery upon it. And then you had to do that on [all the different versions of MacOS, such as] Tiger and Leopard and Snow Leopard and Lion, and also on the Power PC and on Intel and in 32 bits and 64 bits ...

Excellence is the sum of 100 or 1,000 of these little details. We care deeply about making something that's excellent from an engineering standpoint even

50



though other companies might decide that, say, Linux support is not an economical thing to devote resources to.

Your company has worried over perfecting version control. One option in Dropbox, called “Packrat,” even allows users to save every version they’ve ever made of a file. Why do you have this emphasis?

Since computers have existed, every user has had this feeling that they’re one click or keystroke away from disaster. We were trying to imagine, “What if you were to build a universal Undo button?” Building a universal undo turned out to mean that we had to invent our own file system, but the way we designed it made it pretty easy to record past versions of files and keep them around.

What has been the biggest challenge of scaling to reach so many users so quickly?

It’s easy to make a solution that works 80 or 90 percent of the time, or even 99 percent of the time. But sooner or later, if the day comes where you’re about to present before an audience and the PowerPoint is not there, you’ll stop using the service—and you’ll tell all your friends what a terrible experience you’ve had.

You talk very winningly about reliability and trustworthiness. But what happened last year when all accounts on Dropbox could be accessed, however briefly, without passwords?

In short, there was a code update that was bad. It wasn’t caught by the mechanisms that are meant to catch such things. You can imagine that was pretty much the nightmare scenario for us. In response, obviously, we did all kinds of work to make sure that kind of thing never happened again.

And you wrote to each of the 54 users who were affected, gave them your cell phone number, and personally apologized.

The number was somewhere in that neighborhood. But yeah, I did.

Your business model is what’s called “freemium.” When I sign up, I get two gigabytes of data storage free. For more storage, and for some options, I must pay [\$10 a month for 50 gigs or \$20 for 100, although users can be given up to eight additional gigabytes for referring new customers to Dropbox]. Do you really believe that enough people will find two gigs constraining? I’ve read that 96 percent of your users pay nothing at all.

In the literal sense it’s just more space, but from an experiential standpoint the real value is having all your stuff in your dropbox instead of, say, only your documents. You can have your whole life in there—with you, wherever you are.

“You’re going to see that the value that comes out of Dropbox is more and more the stuff that other people build. Whether it’s your TV or your camera or the apps on your phone, we want to make it easy for anything that consumes or creates data to be able to plug in. What we’re really trying to build is the Internet’s file system.”

Will Dropbox one day become more than a network for file sharing?

Absolutely. The explosion of mobile devices means that the world needs an elegant solution for the new problems people have. It needs a fabric that ties together all of their devices, services, and apps. Even though today people may think of Dropbox as a magic folder on their desktop, what we’re really excited about is the opportunity to make all this other stuff you use better. We envision little Dropbox icons everywhere, analogous to the Facebook icons you see everywhere. When you take a picture, it should save your photo to your dropbox; and when you make a to-do list on your iPhone, it should save the list to your dropbox. Any app or device should be able to plug into Dropbox and have access to all your stuff, because that’s where it resides.

This future Dropbox is an example of an overused word: a “platform” with which

many software developers and hardware manufacturers will work.

Over the next years you’re going to see that the value that comes out of Dropbox is more and more the stuff that other people build. Whether it’s your TV or your camera or the apps on your phone, we want to make it easy for anything that consumes or creates data to be able to plug in. What we’re really trying to build is the Internet’s file system.

We’re far from that. It’s a mess now, right?

Yes. Think of the idea of the connected home. I just moved into a new apartment,

and I have this new audiovisual equipment, and the TV has Wi-Fi and the receiver has an Internet jack on the back—but the downside is that I feel like I have 10 ways to watch Netflix badly.

Everything is jockeying to be at the center of the universe at the expense of the user experience. We think we have a lot to contribute here.

Well, we wish you well. But doesn’t competition from Apple’s iCloud service give you pause? There is a company that also sweats the smallest technical details.

I think they’ve demonstrated that they fundamentally care about making the Apple experience really good, but they don’t pay nearly the same attention to other platforms. Even if you’re an Apple user, what happens when you need to share with someone who has an Android phone or you have to work with someone who has a Windows PC? **It**

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The energy-efficient ES 750G

The ES 750G boasts innovative power-saving outlets, which automatically shut off power to controlled outlets when the computer plugged into the host outlet is deemed asleep, eliminating wasteful electricity drains.

- 10 outlets
- 450 watts/750 VA
- 70 minutes maximum runtime
- Coax and telephone/network protection



The best-value ES 550G

The ES 550 uses an ultra-efficient design that consumes less power during normal operation than any other battery backup in its class, saving you money on your electricity bill.

- 8 outlets
- 330 watts/550 VA
- 43 minutes maximum runtime
- Telephone protection



APC
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PHOTO ESSAY

The Other Side of CES

Every January, up to 150,000 people swarm the Consumer Electronics Show in Las Vegas, where they mainly see salesmen and models touting slick gadgets under bright lights. Most visitors miss the surprises that can be found in a plain corner called the “International Gateway,” where manufacturers from Asia display unglamorous components and offbeat items.

By BRIAN BERGSTEIN *Photographs by* GREGG SEGAL



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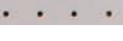
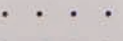
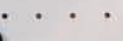
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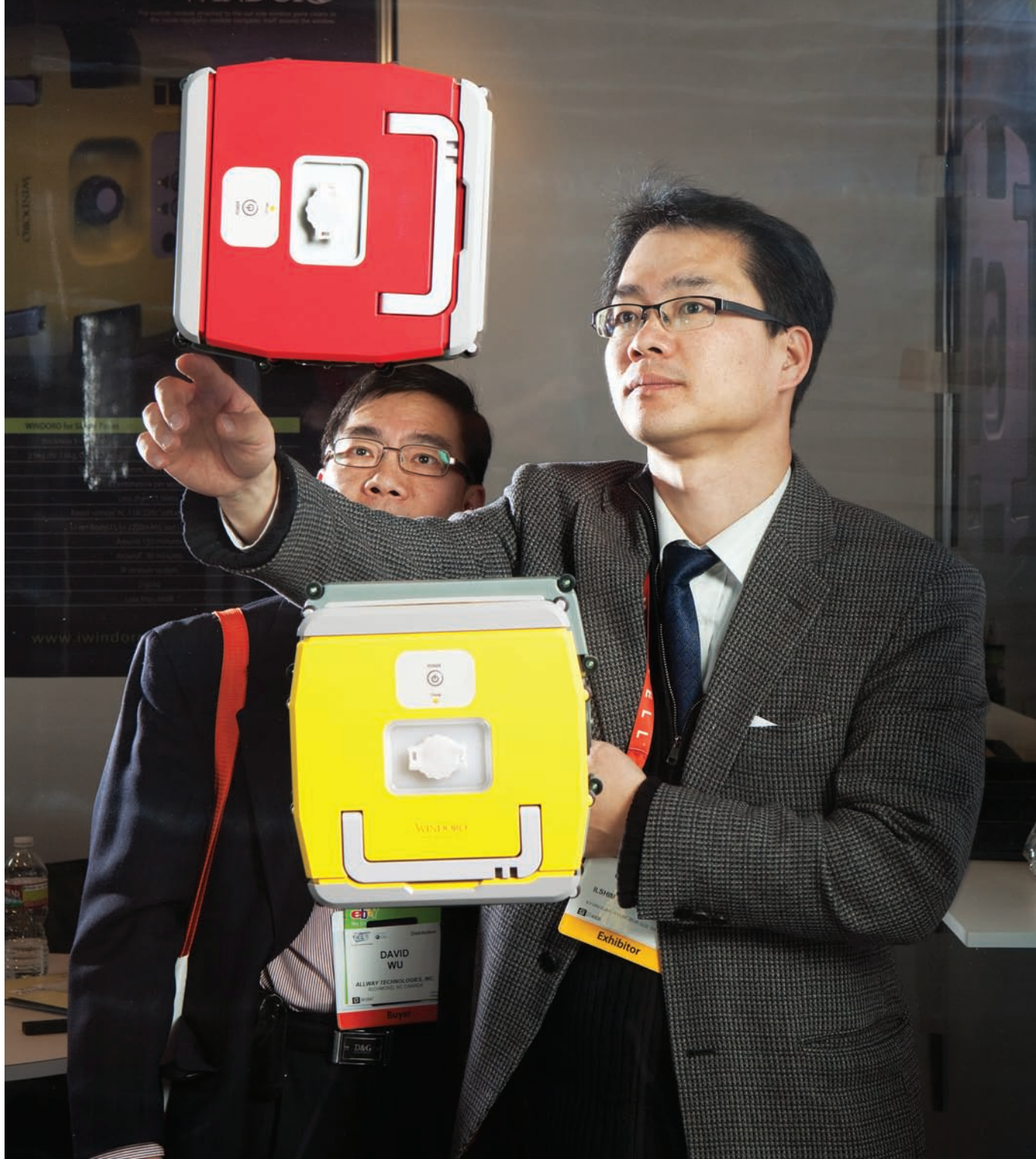
A grid of 20 toy cars, each with a label below it. The labels are: MS-960, MS-974, MS-973, MS-995, MS-945, MS-947, MS-948, MS-949, MS-961, MS-962, MS-963, MS-964, MS965, MS-966, MS-967, MS-968, MS-969, MS-970, MS-971, MS-972.

About a quarter of a mile from the center of the 2012 CES, where models danced to hip-hop in the Soul headphones booth (opposite page), Huang Rong of China's Edtak Electronic sat quietly in his stall in one of the hotel ballrooms that held the International Gateway. He and a colleague hoped to find a U.S. distributor for two products in particular: colorful keyboards for children and \$4 computer mice that look like toy cars.



Ken Siow, the head of sales for Gavio, showed off Wrenz, metal stereo speakers shaped like birds. Gavio is owned by a Singapore company that designs sleek, whimsical accessories. Siow says that by engineering its items itself, Gavio cuts out the usual costly markup on electronics. "I will kick your ass," he said with a huge laugh, "if you buy something that is a few times higher than what it should be."





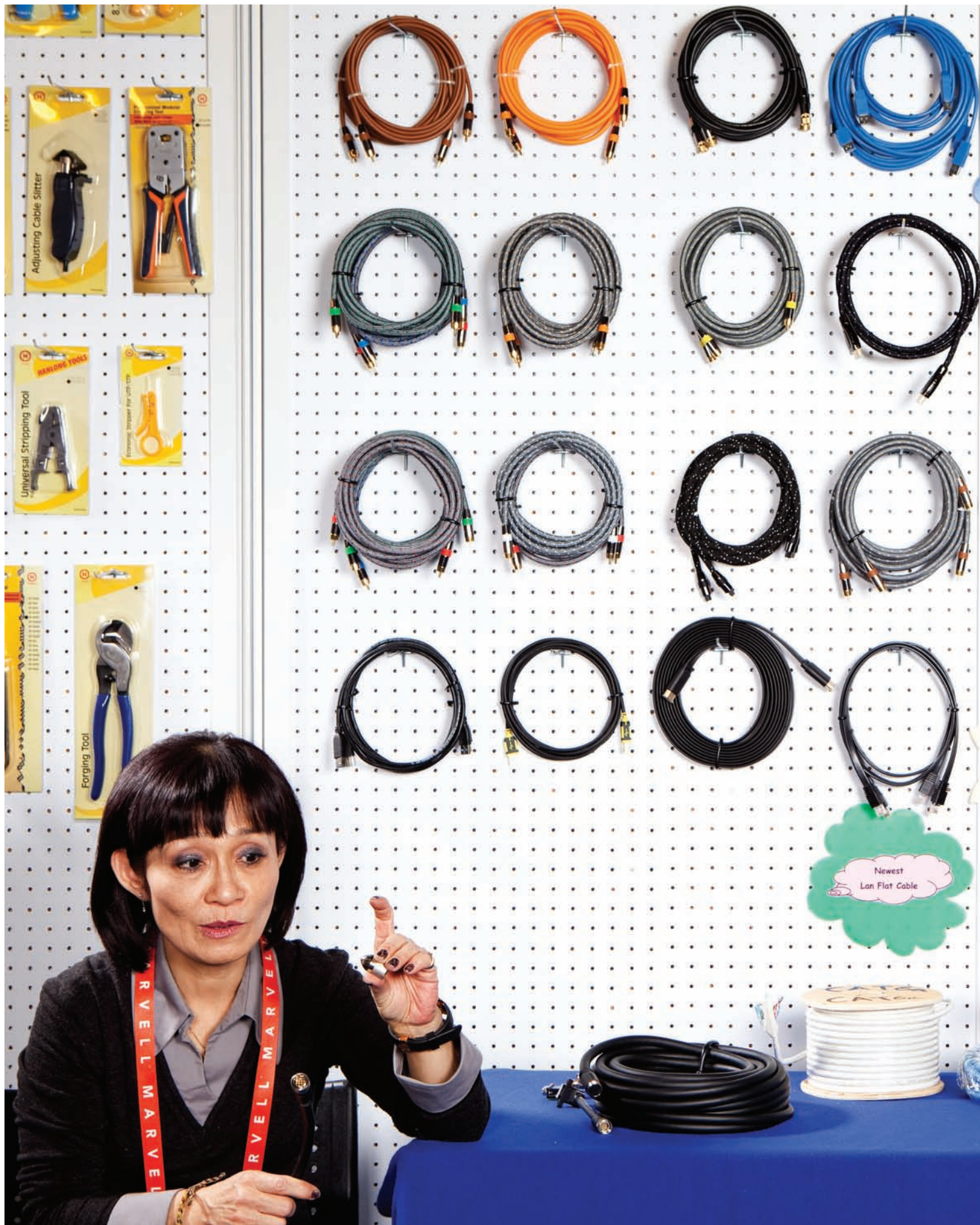
Man Hyun Ryu (right) demonstrated two Windoros for a visitor to the booth of South Korea's Ilshim Global. Much as iRobot's Roomba will vacuum your floor, Ilshim's Windoro will clean your window as it moves across the glass. Each unit has two pieces

held together by magnets—one for the inside of a window and one for the outside. The devices, which sell for about \$450, are available in Japan, Korea, and Europe. They clean one side of a window at a time; Ilshim is developing a version that does both sides.

One morning, Shi “Terry” Liao lamented the fact that exhibitors in the International Gateway were organized not by the products they sell but by the country they came from. “This hall is just Chinese people,” he grumbled. He had come from Jiangmen to find international distributors for the aluminum woofers made by his employer, Golden Dragon Electronic. Liao emphasized that the speakers were designed to fit under car seats instead of having to go in the trunk like other high-end speakers. That afternoon, things were looking up: buyers from Brazil, South Africa, and the United States were asking him for details and nodding approvingly.









Opposite page: Like many exhibitors in the International Gateway, Jennifer Liu, owner of Wealley's Technology, pointed out the finer points of even the humblest components. Wealley's, which is based in Taiwan, makes data cables and connectors and specializes in sturdy wiring that goes behind the walls of buildings.

Above: Tyler Baccari, the U.S. sales representative for Sunway of Shenzhen, China, and the company's owner, Richard Li, model hats that are equipped with LED lights. Sunway was hired to produce the hats for a Finnish inventor who thought they'd be ideal for long winter nights. Li says the inventor told him: "Everyone deserves the right to see and be seen."

www

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The 50 Most Innovative Companies 2012

Our third annual list of the companies leading commercial invention.

By STEPHEN CASS

What is a TR50 company? It is a business whose innovations force other businesses to alter their strategic course. TR50 members are nominated by *Technology Review's* editors, who look for companies that over the last year have demonstrated original and valuable technology, are bringing that technology to market at a significant scale, and are clearly influencing their competitors.

Eighteen of the companies we selected for the 2011 TR50 continue to meet those criteria, and return this year (seven are making their third appearance). Of course, that means that 32 companies we picked for last year's TR50 are no longer on the list.

Sometimes companies fall off the list because of a decline in the prospects of an entire sector. For example, despite being strongly represented in 2010 and 2011, advanced-biofuels companies are absent this year. This sector has generally failed to scale up production to a level that can begin to make serious inroads into the use of conventional oil. While its technology still has potential, it currently has little influence on the direction of the fuel or transportation industries.

In other cases, individual companies lose the vision that made them worthy of the TR50. One such example is Netflix, which we selected

www

Visit www.technologyreview.com/tr50 to see expanded profiles of the TR50 companies.

ENERGY

Alta Devices **New****Private**

Why: Its high-efficiency gallium arsenide-based solar cells provide a way to lower the cost of solar power.

Key innovation: Can economically produce robust cells that use only small amounts of the expensive semiconductor.

Babcock and Wilcox **New****Public**

Why: The company is developing cheaper nuclear reactors.

Key innovation: A simplified modular reactor design decreases size and cost.

First Solar**Public**

Why: It is reducing the cost of utility-scale photovoltaic installations.

Key innovation: First Solar constrains costs with vertical integration of everything from plant construction to the manufacture of high-efficiency cadmium telluride cells.

General Electric **New****Public**

Why: By building flexible and efficient natural-gas power plants, GE is making it easier for utilities to use intermittent sources of renewable energy.

Key innovation: Gas turbines based on jet engines allow power plants to quickly increase or decrease their electricity generation to compensate for variations in wind or solar power.

Goldwind**Public**

Why: It is optimizing wind farms for conditions in China.

Key innovation: Wind turbines are specially adapted for the high altitudes and low wind speeds that characterize Chinese wind resources.

LanzaTech **New****Private**

Why: Makes fuel and chemicals from the carbon monoxide produced by processes such as steelmaking.

Key innovation: Genetically engineered organisms turn the gas into ethanol and other useful chemicals.

Sakti3 **New****Private**

Why: Its high-energy batteries could make electric cars cheaper and improve their range.

Key innovation: Making batteries without the flammable liquid found in conventional electric-car batteries means they can store more energy.

Shell **New****Public**

Why: It has learned to exploit oil resources that were previously impractical to tap.

Key innovation: Has drilled and started production at the world's deepest offshore well.

Siemens**Public**

Why: Its cheaper turbines and installation techniques will make offshore wind plants more affordable.

Key innovation: Gearless turbines and streamlined manufacturing lower capital costs and improve reliability.

Suntech**Public**

Why: Has developed a low-cost way of making better silicon solar cells.

Key innovation: Its new panels are more efficient because they reflect less light and use thinner electrodes that block less light.

COMPUTING

Alcatel-Lucent **New****Public**

Why: Has created a cellular network that can cope with our growing appetite for mobile data.

Key innovation: Its LightRadio architecture uses many small, efficient, and easily upgraded base stations in place of the larger, less efficient cell towers of today.

Apple**Public**

Why: The Siri virtual assistant built into the iPhone 4S demonstrates a new kind of conversational voice-operated interface.

Key innovation: Software that can interpret ambiguous sentences allows Siri to understand even casual commands.

ARM Holdings**Public**

Why: By reducing the electricity demands of data centers, ARM is making cloud computing cheaper.

Key innovation: Its powerful server processors use an architecture originally developed for energy-conscious mobile devices.

Dreamworks Animation **New****Public**

Why: Speeding up production of digitally animated movies will also benefit gaming and augmented reality.

Key innovation: Software that can take maximum advantage of a multicore processor allows animators to create scenes in minutes instead of hours.

IBM**Public**

Why: Its flexible artificial-intelligence systems have the potential to assist people in many areas, such as health care.

Key innovation: Watson, which demonstrated its capability by beating skilled human quiz-show players, learned by automatically digesting text from books and websites, an ability that could be adapted to any area of knowledge.

Nicira**Private**

Why: By using virtual computer networks rather than hardwired systems to connect cloud servers, it could make the cloud more secure and reliable.

Key innovation: Its software takes over the functions of network hardware, resulting in a distributed system of components that can swiftly respond to changes in workload.

Palantir Technologies **New****Private**

Why: Its software can extract common threads from mountains of data, potentially yielding leads for intelligence agencies and police forces.

Key innovation: The software, which can begin analyzing a new data set without extensive preparation, can handle many different types of input, including data from military operations and financial transactions.

Qualcomm **New****Public**

Why: The Mirasol display for mobile devices provides full color even in bright sunlight and uses a fraction as much power as today's phone and tablet displays.

Key innovation: Technology modeled on a butterfly's wing creates a bright image by reflecting and amplifying particular wavelengths of ambient light.

Samsung **New****Public**

Why: Samsung is an increasingly major player in consumer electronics, from iPhone components to new phones, tablets, and OLED TVs; it was the world's top seller of smart phones in 2011.

Key innovation: Tightly integrated design and manufacturing processes result in clever, efficiently produced designs.

Skybox Imaging **New****Private**

Why: Managing natural resources, planning humanitarian missions, and assessing construction projects could all become easier thanks to Skybox's satellites, which will take more frequent images at lower cost.

Key innovation: Its small satellites cost less to build and launch than traditional ones, and its automated analytic software makes it easier for customers to extract useful information.

Square

Private

Why: Small businesses benefit from its simple mobile payment system.

Key innovation: Square has moved beyond its initial credit card reader for smart phones; a new app lets you automatically open a tab with a merchant on entering a store.

Tabula

New

Private

Why: Its processors combine the flexibility of software with the efficiency of hardware.

Key innovation: Chip designs that can reconfigure themselves faster than existing reprogrammable designs make smaller, cheaper chips possible.

Taiwan Semiconductor

New

Public

Why: A manufacturing process specifically designed for smart-phone and tablet processors will produce chips that increase computing performance without guzzling power.

Key innovation: Its new materials avoid the leakage of current that saps the energy efficiency of other high-performance processors with very small features.

WEB & DIGITAL MEDIA

Bluefin Labs

New

Private

Why: It mines social-media sites to gauge the audience response to television shows and advertising.

Key innovation: Natural-language analysis of comments on social-media sites provides fine-grained information about audience size and sentiment.

Dropbox

New

Private

Why: Its technology makes it easier for users to sync and share files on smart phones, laptops, and desktops.

Key innovation: Cloud-based systems are the basis for a consumer-focused service that works across multiple platforms.

Facebook

Private

Why: The social network has become the means by which many online users communicate, get news, and find entertainment.

Key innovation: New features automatically integrate casual online activity, such as listening to music or reading newspaper articles, into the social sphere.

Google

Public

Why: Despite its lukewarm performance in social media, Google's willingness to move into new areas shows it can still be an agenda-setter.

Key innovation: The introduction of Android 4.0 (also known as "Ice Cream Sandwich"), with its crowd-pleasing interface, confirms the company's position as a major force in mobile computing.

OnLive

New

Private

Why: Allows users to access applications too powerful for their hardware to support.

Key innovation: Its video streaming technology minimizes lag so that applications running on a server appear to be running locally.

Safaricom

New

Public

Why: Has deployed mobile health services over Kenya's cellular network.

Key innovation: Through cell phones, the company offers services such as first-aid recommendations for subscribers.

Spotify

New

Private

Why: Its digital music subscription service has succeeded where others have failed or had only lackluster results.

Key innovation: Spotify has negotiated with record labels to allow users access to a large library of music one track at a time; they can even download music for offline use.

Twitter

Private

Why: Microblogging has become a ubiquitous adjunct to major events, from earthquakes to revolutions.

Key innovation: A redesigned mobile application encourages users to discover content relevant to them while remaining within the ambit of Twitter rather than turning to third-party systems.

Zynga

Public

Why: Social gaming has dramatically expanded the demographic appeal of computer games and created new business models for game companies.

Key innovation: Zynga has mastered the art of giving away games and then persuading players to make in-game purchases of virtual goods, sometimes adding up to many times the typical purchase price of a game.

MATERIALS

Applied Materials

Public

Why: A key supplier of equipment for making solar cells, it is helping to lower the cost of solar power.

Key innovation: A new manufacturing system allows solar producers to increase the output and efficiency of their cells.

EADS

New

Public

Why: Using lightweight parts will decrease the fuel consumption of the company's aircraft and make its satellites cheaper to launch.

Key innovation: Redesigning select parts to take advantage of the capabilities of 3-D printers has cut their weight in half.

Intel

New

Public

Why: Has reinvented transistor architecture as it continues to shrink the size of devices on a chip.

Key innovation: Its 3-D transistors will be used in a new generation of 22-nanometer chips.

Siluria

New

Private

Why: Its catalytic process is able to convert cheap and abundant natural gas into ethylene, a commodity chemical used to make plastic.

Key innovation: Developed a family of catalysts that selectively cause methane to react to form ethylene.

Wildcat Discovery

New

Private

Why: Has used high-speed methods to find materials that improve the performance of batteries.

Key innovation: Identified a pair of materials that could increase energy density by 25 percent in batteries for cars and portable electronics.

TRANSPORTATION

Better Place

New

Private

Why: Its new infrastructure extends the effective range of electric vehicles.

Key innovation: Has designed and installed battery swap stations, a charging network, and a central control station to manage a fleet of electric cars in Israel.

SpaceX

Private

Why: Its spacecraft and rockets could replace expensive government vehicles as a way into orbit.

Key innovation: The reusable Dragon cargo capsule is set to become the first private spacecraft to visit the International Space Station.

WiTricity

New

Private

Why: WiTricity is making it more convenient to charge electric cars.

Key innovation: Its system can recharge a battery pack wirelessly.

BIOMEDICINE

Athenahealth **New****Public**

Why: Its systems help doctors and patients with the morass of medical records and billing paperwork.

Key innovation: Developed cloud-based software for electronic health records and practice management.

Cellular Dynamics**Private**

Why: Using human iPS cells in drug screening could accelerate the development of new therapies.

Key innovation: Its new product derived from iPS cells is meant for use in vascular targeted drug discovery, tissue regeneration, and life science research.

Complete Genomics**Public**

Why: New sequencing projects that the company announced in 2011 include one aimed at predicting preterm births and another that will sequence cancer genomes.

Key innovation: A computational platform allows it to assemble DNA sequences into genomes more accurately.

Foundation Medicine **New****Private**

Why: Its new diagnostics exploit a growing understanding of the molecular basis of cancer.

Key innovation: It has developed a comprehensive cancer diagnostic test and is partnering with pharmaceutical companies to use the test in drug development.

Healthpoint Services **New****Private**

Why: It is using telemedicine techniques to deliver health care to rural India.

Key innovation: Its network of eight centers brings advanced telemedicine systems to patients.

Integrated Diagnostics **New****Private**

Why: By reducing the cost of diagnostic tests, it has allowed the monitoring of more disease markers.

Key innovation: Its synthetic antibodies replace more expensive antibodies widely used in diagnostics.

Life Technologies**Public**

Why: Lowering the cost of DNA sequencing opens the door to more genetically targeted treatments and diagnostics.

Key innovation: Its benchtop sequencer can sequence a human genome in one day, at a cost of just \$1,000 per genome.

Organovo **New****Private**

Why: Its three-dimensional artificial tissue structures can be used for drug testing and are likely to find therapeutic applications.

Key innovation: A printing process methodically deposits layers of cells and gel material to build up new tissues.

PatientsLikeMe **New****Private**

Why: Online social connections and shared data offer a new way to improve the understanding and treatment of disease.

Key innovation: Published a peer-reviewed study, based on data volunteered by site users, that countered the results of a clinical trial assessing the effects of lithium on ALS, or Lou Gehrig's disease.

Roche**Public**

Why: Its new drugs target genetic mutations in cancer cells.

Key innovation: Developed a lung-cancer drug and a diagnostic test for the mutation that makes some cancers susceptible to the drug.

last year for piggybacking a video-on-demand service onto its existing DVD-by-mail subscriptions. Netflix had already disrupted the business model of brick-and-mortar video rental stores and cleverly maneuvered to prevent itself from being disrupted in turn by streaming video technology. But later in 2011, the company tried to split the streaming side of its operations from its DVD service, an ill-fated decision that provoked public ridicule and the loss of hundreds of thousands of subscribers before the company reversed course. Suddenly, Netflix wasn't able to clearly dictate its own agenda, let alone that of the entertainment industry.

With still other companies, it's not the vision but the execution that is lacking. If the selection process for the TR50 had occurred a few months earlier, we probably would have included Amazon on the list (as we had the previous two years), citing the release of the Kindle Fire. The Fire initially looked like a serious competitor to the iPad for dominance of the tablet computing market. Even though it had fewer functions than the iPad, it cost much less and made clever use of Amazon's extensive cloud infrastructure. But as consumers racked up more daily experience with the device, more than a few of them found their initial satisfaction turning to disappointment. Many of the things the Fire was supposed to do, it didn't do well enough; customers complained of connectivity problems or difficulties with the touch-screen navigation. Although the company has released software patches that it claims will address most users' concerns, launching a product that frustrated many customers showed that Amazon is still a challenger rather than a leader when it comes to merging consumer electronics with the cloud.

Finally, some companies fell off the list simply because they were crowded out by others with big new ideas. Some of these newcomers are shaking up established fields. Dropbox has made its mark in the previously sleepy world of online storage. Babcock and Wilcox is developing small reactors that could change the regulatory and economic calculus of nuclear power. And Athenahealth is reinventing health insurance as an exercise in information technology.

Still others are breaking into new territory. PatientsLikeMe is transforming the notion of how a clinical trial must be conducted by encouraging patients with chronic conditions to share intimate details online. EADS is turning 3-D printing (originally created for the production of prototypes) into a full-scale manufacturing technology. And LanzaTech is turning carbon monoxide emissions into fuel.

As a group, the TR50 companies represent our best judgment of the commercial innovations most likely to change lives around the world. Do you agree with us? Which companies that didn't make it onto the list should have, and which do you think didn't deserve a place? Let us know at www.technologyreview.com/tr50. **tr**

STEPHEN CASS IS THE SPECIAL PROJECTS EDITOR OF TECHNOLOGY REVIEW.

A New Net

A startup called Nicira is reinventing computer networking with an audacious goal: to make all kinds of Internet services smarter, faster, and cheaper.

By TOM SIMONITE

In 2003 Martín Casado found himself with no small challenge on his hands: he needed to reinvent the technology that underpins the Internet. It had been developed decades earlier and was proving unsuited to an era of cyberwarfare.

Casado, then a researcher at Lawrence Livermore National Laboratory, had been approached by a U.S. intelligence agency with a thorny problem. Computer networking technology allowed intelligence agents and other government workers worldwide to stay connected to one another at all times. Field agents could instantly share data seized in a raid with experts anywhere in the world. But the fact that so many computer networks were enmeshed also aided enemy hackers. Once they gained entry to one system, they could hop across networks to search for other treasures. The agency (Casado won't say which one) told him it wanted to keep its large network but reserve the ability to temporarily close off parts of it for crucial transmissions, creating a data equivalent of the dedicated telephone hotline that used to link the White House and the Kremlin.

Casado ultimately realized that he couldn't help. Partly because the Internet was created with unreliable equipment, its creators had wanted to make sure that it would work even if some parts malfunctioned. Thus, the networking hardware all operated independently and without central control. That's good if you want information to keep flowing in dire circumstances, but it's not so good if you want the option of isolating a specific communication channel within that network so as to keep secrets secret. For Casado to do what the intelligence agency wanted, each piece of hardware in a network would have to be reconfigured in a slow and manual process. "We hacked something together which in the end didn't give us the properties they wanted," he says.

That humbling experience has shaped his life since. Haunted by the problem, he soon left Livermore and entered grad school at Stanford University to search for an answer. He presented one in his 2007 PhD thesis, which proposed a radical new way for computer networks to operate. Now he's cofounded a company called Nicira, which is poised to use that idea to make the Internet more



OUT OF THE BOX With his startup, Nicira, Martín Casado intends to make Internet services slicker by rewriting some of the rules of computer networking.

powerful than ever before. Nicira's technology won't just help intelligence agencies keep secrets. It should also improve the security, lower the price, and increase the power of any technology that uses the Internet, unlocking innovation that is too expensive or technically impossible to achieve today. Along the way, Nicira (the name is pronounced "Nis-ee-ra" and means "vigilant" in Sanskrit) could very well upend some of the world's largest technology companies.

OVERDUE INNOVATION

Casado is 35 and has near-black hair with the faintest flecks of gray. He can appear intense, even nervous, but he is eloquent, with a friendly, didactic manner that shows evidence of five years teaching Stanford undergrads. He also has the steely determination required to run 100 miles in less than two days, something he has done more than four times as a devotee of the grueling sport known as ultrarunning.

His determination has surely helped during years spent arguing that one of the most successful and ubiquitous technologies of all time needs to be rethought. Stanford researchers have reshaped computing before—both Google and early work on the Internet itself came out of their labs—but Casado and his PhD supervisor, Nick McKeown (also a close friend), found their ideas initially unappreciated and even derided by other computer scientists. "When we first published, they thought we were nutty," Casado recalls. "We submitted a paper and were literally made fun of in the reviewers' comments. They said, 'This will never work.'"

The crux of that supposedly unworkable idea was to take away the stubborn independence of the network hardware. All those routers and switches would take orders from one central piece of software; a single command could then reconfigure every piece of a network.

Casado's PhD thesis showed that it was possible. By writing software that could reprogram routers and switches, he was able to turn computer networks into the secure channels that he had been asked for back in 2003. A different intelligence agency put up the money for further trials of the technology, and in 2007 Casado, McKeown, and Berkeley professor Scott Shenker founded Nicira. Rich entrepreneurs and three of Silicon Valley's most prestigious venture capital funds soon put in money of their own.

That enabled Casado and his engineers to push the technology a crucial step further. To avoid having to install their special software on network hardware, they used a trick known in computer science as virtualization, which creates a software replica of a piece of hardware—but the software does the job more intelligently. In Nicira's case, software running on server computers could simulate programmable routers and switches. The physical devices themselves could fade in importance entirely. After four years of quiet hard work, Nicira has just launched that software as its first product. It should trigger a new wave of Internet innovation in everything from mobile apps to online banking security.

That potential is not obvious to a casual observer. The product is clunkily named Network Virtualization Platform. It's aimed at the operators of data centers, the computer-stuffed warehouses that run Internet services and websites. Casado freely admits that it is hard to impress a layperson with his technology: "People do struggle to understand it," he says.

But Nicira, which has received \$50 million in funding and filed nearly 50 patents, is taking on a problem that limits what the Internet can offer all of us.

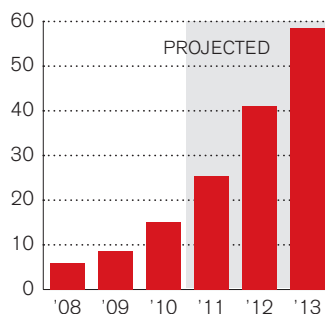
The problem is this: cloud computing, even though it now might be a household term, hasn't lived up to its hype—and as things now stand, it can't. It was supposed to turn computing power into a cheap utility, like electricity after the advent of power stations and a national grid. A relatively small number of companies would offer computing resources by running software in vast, efficient data centers and piping the results over the Internet to anyone, any-

where. That would push down the price of services that rely on computing and allow them to become more sophisticated.

Yet today, even with seemingly cost-effective cloud services available from the likes of Amazon, most companies still choose to operate their own computing resources—whether for corporate e-mail or financial trading—as if they were homeowners relying on generators for electricity. One reason they resist cloud computing, Casado says, is that network architecture is too decentralized to reconfigure

A GROWING OPPORTUNITY

Revenue from "public cloud" services, in billions of dollars



Source: Forrester Research

easily, which leaves the cloud insecure and unreliable. Cloud computing providers tend to run entire data centers on one shared network. If, for example, Coke and Pepsi both entrusted their computer systems to one of today's public cloud services, they might share a network connection, even though their data stores would be carefully kept separate. That could pose a security risk: a hacker who accessed one company's data could see the other's. It would also mean that a busy day for Coke would cause Pepsi's data transfers to slow down.

All of that changes when Nicira's software is installed on the servers in a data center. The software blocks the applications or programs running on the servers from interacting with the surrounding network hardware. A virtual network then takes over to do what a computer network needs to do: it provides a set of connections for the applications to route data through. Nicira's

Any big change to the status quo produces losers as well as winners. But when asked who might be a victim of Nicira's success, the executives exchange quick glances and are careful not to name any companies. They're being diplomatic.

virtual network doesn't really exist, but it's indistinguishable from one made up of physical routers and switches.

To describe the power this gives to cloud administrators, Casado uses a Hollywood reference. "We actually give them the Matrix," he says. The movie's Matrix manipulated the brains of humans floating in tanks to provide the sensation that they were walking, talking, and living in a world that didn't exist. Nicira's version pulls a similar trick on the programs that reside on a server inside a data center, whether they are running a website or a phone app. In practice, this means that administrators can swiftly reprogram the virtual network to offer each application a private connection to the rest of the Internet. That keeps data more secure, and Coke's data crunch would affect Coke alone. It also lets the cloud provider set up automatic controls that compensate for events like sudden spikes in demand.

Ben Horowitz, a partner in the investment firm Andreessen-Horowitz, says he and his partner Marc Andreessen, a cofounder of Netscape, quickly realized that Nicira was delivering something long overdue in computing. "The total lack of innovation in networking compared to operating systems or storage had been bothering us for a while," he says. "It was holding back the industry." After meeting Casado, Horowitz invested in Nicira and joined its board. He saw in Nicira echoes of VMware, a company that helped set off the cloud computing boom and has a market capitalization of \$40 billion. VMware's software creates virtual computers inside a server, boosting the efficiency of data centers and driving down the cost of servers. Nicira's software promises a similar instant upgrade to what a data center can do, by removing the efficiency bottleneck imposed by networks.

FREEDOM OF MOVEMENT

Nicira already has roughly a dozen customers, all of them large companies that offer services over the Internet. Several, such as Rackspace and Japan's NTT, the world's second-largest telecommunications provider, rent out clouds to other companies, a model known as the "public cloud." Nicira's biggest opportunity lies in helping such landlords fix the security and reliability problems that discourage large companies from using the public cloud, says Steve Mullaney, a veteran executive in the networking business who joined Nicira as chief executive in 2009, freeing Casado to be CTO. Mullaney left a VP position at Palo Alto Networks, a network security startup on track for a large IPO, because he saw in Nicira

"the chance to do something really big." The public cloud is now used by small and medium-sized business and new ones like the social-gaming company Zynga, says Mullaney, but getting very large enterprises to follow suit promises "the big money." An estimated \$26 billion a year is spent on the public cloud today, according to Forrester Research. Mullaney thinks the market would expand significantly if businesses, which spend \$2 trillion a year worldwide on IT infrastructure, were more inclined to trust this technology.

The Matrix-like control that Nicira offers should also make the Internet more reliable. After the Fukushima-Daichi nuclear disaster in Japan last March, electricity rationing and scarce supplies of diesel for generators trapped some Web services offline in powerless data centers. Last August NTT showed that Nicira's technology could have kept those systems active by moving them rapidly elsewhere. In tests, software was smoothly transferred between data centers 30 miles apart without even having to stop the programs from running. Even as NTT's software moved to new physical hardware, Nicira's technology maintained the illusion that nothing had changed. "We can move like liquid between data centers ahead of brownouts," says Casado. Making such transfers without Nicira's technology would mean laboriously reprogramming network hardware and turning off the system being protected from the brownout.

Such flexibility could also make it cost-effective for companies to call on the cloud only in the circumstances when they need it most. Many online retailers today, Mullaney says, use roughly 40 percent of their computing infrastructure just to handle seasonal rushes, leaving it idle for most of the year. Nicira speeds the process of moving into the rented cloud to such an extent that a company could scrap that idle hardware and turn to the cloud temporarily when traffic surges. That would keep it from having to buy equipment that draws electricity even when idle. In a more futuristic energy-saving scenario, customers' virtual networks could migrate from one data center to another around the world, temporarily settling wherever power and cooling cost least.


And just as Keanu Reeves's character in *The Matrix* tweaks the virtual world to halt enemy bullets, Nicira's virtual networks could "change the laws of physics" for an attacker who gained access to a computer connected to one of them, Casado says. Computers' apparent location, their apparent activities, and the type of traffic they appear to be handling could all be altered to confuse a hacker. "You have this full God-like control," he says.

Any big change to the status quo produces losers as well as winners. But when asked who might be a victim of Nicira's success, Casado and Mullaney, sitting in Nicira's boardroom, exchange quick glances and are careful not to name any companies—even Cisco Systems, the world's leading maker of routers and switches. They're being diplomatic; Nicira has already recruited engineering and executive talent from Cisco, and Nicira's technology poses an even bigger threat. Cisco and other big networking companies, such as Juniper, market their routers and switches on the strength of the intelligence built into the chips inside, which is difficult to modify. In Nicira's world, however, a network's intelligence resides in its control software, and any network hardware will do—the cheaper the better. “A few years out, if I'm buying network infrastructure I just want the price to be right,” says Casado. Recall what happened to the price of computer hardware in the personal-computing boom of the early 1980s. IBM's PC standard separated hardware and software, making operating systems like Microsoft Windows the focus of innovation while hardware became a race-to-the-bottom commodity. Cisco and other vendors of traditional networking equipment will need to adapt, fast.

For its part, Cisco has introduced virtual versions of some data-center hardware, which offer greater flexibility than its traditional products. Yet it disputes the idea that this approach means hardware will be devalued. Guru Chahal, a director of product management in the Cisco group that works on virtualization, agrees that networks need to become more configurable. But he says that the solution will be to design hardware and software together. “At the end of the day, packets—data—are being forwarded by hardware,” Chahal says.

Nicira's team is far from alone in seeking to overhaul the way we shuttle data around. Casado's academic collaborators at Stanford, Berkeley, and elsewhere are rapidly ramping up new projects in a field that has become known as software-defined networking, or SDN. (The term was coined by *Technology Review* when Casado and McKeown's work at Stanford was featured in the TR10 in March/April 2009.) A handful of other startups are getting funded to commercialize their own ideas, while large companies like Hewlett-Packard and IBM are creating network hardware that's designed to be more programmable.

But Nicira is establishing itself more quickly than other startups. In addition to NTT and Rackspace, its customers include AT&T, Deutsche Telekom, Fidelity Investments, and eBay. And in Casado, Nicira has a figure widely recognized by competitors and colleagues alike as a fierce talent who has generated and proved many of the very ideas now gaining traction.

Internet technology has brought us a long way in 25 years, but the time has come for it to grow up, he says. “Today it needs all this midwifing and manual care and feeding. That has to change.” 

TOM SIMONITE IS AN IT EDITOR AT *TECHNOLOGY REVIEW*.

The Cancer Test

Foundation Medicine is offering a test that helps oncologists choose drugs targeted to the genetic profile of a patient's tumor cells. Has personalized cancer treatment finally arrived?

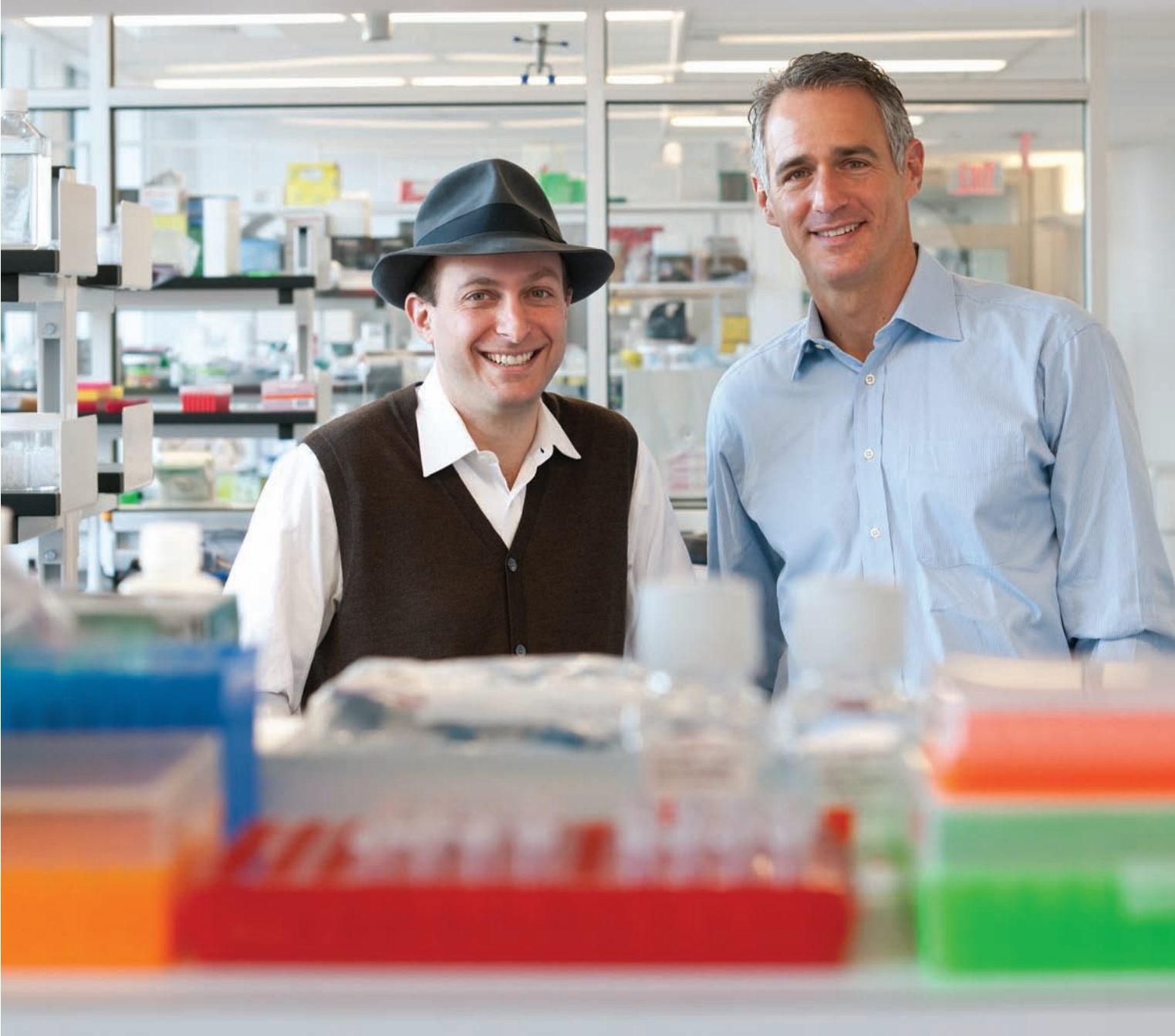
By ADRIENNE BURKE

Michael Pellini fires up his computer and opens a report on a patient with a tumor of the salivary gland. The patient had surgery, but the cancer recurred. That's when a biopsy was sent to Foundation Medicine, the company that Pellini runs, for a detailed DNA study. Foundation deciphered some 200 genes with a known link to cancer and found what he calls “actionable” mutations in three of them. That is, each genetic defect is the target of anticancer drugs undergoing testing—though not for salivary tumors. Should the patient take one of them? “Without the DNA, no one would have thought to try these drugs,” says Pellini.

Starting this spring, for about \$5,000, any oncologist will be able to ship a sliver of tumor in a bar-coded package to Foundation's lab. Foundation will extract the DNA, sequence scores of cancer genes, and prepare a report to steer doctors and patients toward drugs, most still in early testing, that are known to target the cellular defects caused by the DNA errors the analysis turns up. Pellini says that about 70 percent of cases studied to date have yielded information that a doctor could act on—whether by prescribing a particular drug, stopping treatment with another, or enrolling the patient in a clinical trial.

Photograph by CHRISTOPHER HARTING

IT'S PERSONAL NOW
Alexis Borisy (left) and
Michael Pellini lead an
effort to make DNA data
available to help cancer
patients.



The idea of personalized medicine tailored to an individual's genes isn't new. In fact, several of the key figures behind Foundation have been pursuing the idea for over a decade, with mixed success. "There is still a lot to prove," agrees Pellini, who says that Foundation is working with several medical centers to expand the evidence that DNA information can broadly guide cancer treatment.

Foundation's business model hinges on the convergence of three recent developments: a steep drop in the cost of decoding DNA, much new data about the genetics of cancer, and a growing effort by pharmaceutical companies to develop drugs that combat the specific DNA defects that prompt cells to become cancerous. Last year, two of the 10 cancer drugs approved by the U.S. Food and Drug Administration came with a companion DNA test (previously, only one drug had required such a test). So, for instance, doctors who want to prescribe Zelboraf, Roche's treatment for advanced skin cancer, first test the patient for the BRAFV 600E mutation, which is found in about half of all cases.

About a third of the 900 cancer drugs currently in clinical trials could eventually come to market with a DNA or other molecular test attached, according to drug benefits manager Medco. Foundation thinks it makes sense to look at all relevant genes at once—what it calls a "pan-cancer" test. By accurately decoding cancer genes, Foundation says, it uncovers not only the most commonly seen mutations but also rare ones that might give doctors additional clues. "You can see how it will get very expensive, if not impossible, to test for each individual marker separately," Foundation Medicine's COO, Kevin Krenitsky, says. A more complete study "switches on all the lights in the room."

So far, most of Foundation's business is coming from five drug companies seeking genetic explanations for why their cancer drugs work spectacularly in some patients but not at all in others. The industry has recognized that drugs targeted to subsets of patients cost less to develop, can get FDA approval faster, and can be sold for higher prices than traditional medications. "Our portfolio is full of targets where we're developing tests based on the biology of disease," says Nicholas Dracopoli, vice president for oncology biomarkers at Janssen R&D, which is among the companies that send samples to Foundation. "If a pathway isn't activated, you get no clinical benefit by inhibiting it. We have to know which pathway is driving the dissemination of the disease."

Cancer is the most important testing ground for the idea of targeted drugs. Worldwide spending on cancer drugs is expected to reach \$80 billion this year—more than is spent on any other type of medicine. But "the average cancer drug only works about 25 percent of the time," says Randy Scott, executive chairman of the molecular diagnostics company Genomic Health, which sells a test that examines 16 breast-cancer genes. "That means as a society we're spending \$60 billion on drugs that don't work."

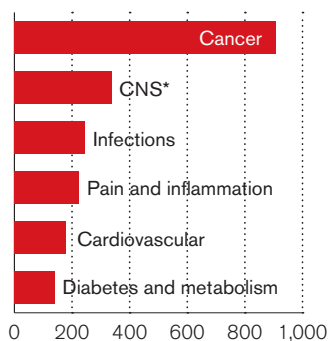
Analyzing tumor DNA is also important because research over the past decade or so has demonstrated that different types of

tumors can have genetic features in common, making them treatable with the same drugs. Consider Herceptin, the first cancer drug approved for use with a DNA test to determine who should receive it. The FDA cleared it in 1998 to target breast cancers that overexpress the *HER2* gene, a change that drives the cancer cells to multiply. The same mutation has been found in gastric, ovarian, and other cancers—and indeed, in 2010 the drug was approved to treat gastric cancer. "We've always seen breast cancer as breast cancer. What if a breast cancer is actually like a gastric cancer and they both have the same genetic changes?" asks Jennifer Obel, an oncologist in Chicago who has used the Foundation test.

The science underlying Foundation Medicine had its roots in a 2007 paper published by Levi Garraway and Matthew Meyerson, cancer researchers at the Broad Institute, in Cambridge, Massachusetts.

CANCER IN THE RX PIPELINE

Drugs in development, 2010



*Central nervous system
Source: Medco

They came up with a speedy way to find 238 DNA mutations then known to make cells cancerous. At the time, DNA sequencing was still too expensive for a consumer test—but, Garraway says, "we realized it would be possible to generate a high-yield set of information for a reasonable cost." He and Meyerson began talking with Broad director Eric Lander about how to get that information into the hands of oncologists.

In the 1990s, Lander had helped start Millennium Pharmaceuticals, a genomics company that had boldly promised to revolutionize oncology using similar genetic research. Ultimately, Millennium abandoned the idea—but Lander was ready to try again and began contacting former colleagues to "discuss next steps in the genomics revolution," recalls Mark Levin, who had been Millennium's CEO.

Levin had since become an investor with Third Rock Ventures. Money was no object for Third Rock, but Levin was cautious—diagnostics businesses are difficult to build and sometimes offer low returns. What followed was nearly two years of strategizing between Broad scientists and a parade of patent lawyers, oncologists, and insurance experts, which Garraway describes as being "like a customized business-school curriculum around how we're going to do diagnostics in the new era."

In 2010, Levin's firm put \$18 million into the company; Google Ventures and other investors have since followed suit with \$15.5 million more. Though Foundation's goals echo some of Millennium's, its investors say the technology has finally caught up. "The

vision was right 10 to 15 years ago, but things took time to develop,” says Alexis Borisy, a partner with Third Rock who is chairman of Foundation. “What’s different now is that genomics is leading to personalized actions.”

One reason for the difference is the falling cost of acquiring DNA data. Consider that last year, before his death from pancreatic cancer, Apple founder Steve Jobs paid scientists more than \$100,000 to decode all the DNA of both his cancerous and his normal cells. Today, the same feat might cost half as much, and some predict that it will soon cost a few thousand dollars.

So why pay \$5,000 to know the status of only about 200 genes? Foundation has several answers. First, each gene is decoded not once but hundreds of times, to yield more accurate results. The company also scours the medical literature to provide doctors with the latest information on how genetic changes influence the efficacy of specific drugs. As Krenitsky puts it, data analysis, not

agrees that patents could pose problems for a pan-cancer test like Foundation’s. That’s one reason Foundation itself has been racing to file patent applications as it starts to make its own discoveries. Pellini says the goal is to build a “defensive” patent position that will give the company “freedom to operate.”

Another obstacle is that the idea of using DNA to guide cancer treatment puts doctors in an unfamiliar position. Physicians, as well as the FDA and insurance companies, still classify tumors and drug treatments anatomically. “We’re used to calling cancers breast, colon, salivary,” says oncologist Thomas Davis, of the Dartmouth-Hitchcock Medical Center, in Lebanon, New Hampshire. “That was our shorthand for what to do, based on empirical experience: ‘We tried this drug in salivary [gland] cancer and it didn’t work.’ ‘We tried this one and 20 percent of the patients responded.’”

Now the familiar taxonomy is being replaced by a molecular one. It was Davis who ordered DNA tests from several companies for

Borisy estimates that Foundation will process 20,000 samples this year. At \$5,000 per sample, it’s easy to see how such a business could reward investors. “That’s ... a \$100-million-a-year business,” says Borisy. “But that volume is still low if this truly fulfills its potential.”


data generation, is now the rate-limiting factor in cancer genomics.

Although most of Foundation’s customers to date are drug companies, Borisy says the company intends to build its business around serving oncologists and patients. In the United States, 1.5 million cancer cases are diagnosed annually. Borisy estimates that Foundation will process 20,000 samples this year. At \$5,000 per sample, it’s easy to see how such a business could reward investors. “That’s ... a \$100-million-a-year business,” says Borisy. “But that volume is still low if this truly fulfills its potential.”

Pellini says Foundation is receiving mentoring from Google in how to achieve its aim of becoming a molecular “information company.” It is developing apps, longitudinal databases, and social-media tools that a patient and a doctor might use, pulling out an iPad together to drill down from the Foundation report to relevant publications and clinical trials. “It will be a new way for the world to look at molecular information in all types of settings,” he says.

Several practical obstacles stand in the way of that vision. One is that some important cancer-related genes have already been patented by other companies—notably *BRCA1* and *BRCA2*, which are owned by Myriad Genetics. These genes help repair damaged DNA, and mutations in them increase the risk of breast or ovarian cancer. Although Myriad’s claim to a monopoly on testing those genes is being contested in the courts and could be overturned, Pellini

the patient with the salivary-gland tumor. “I got bowled over by the amount of very precise, specific molecular information,” he says. “It’s wonderful, but it’s a little overwhelming.” The most promising lead that came out of the testing, he thinks, was evidence of overactivity by the *HER2* gene—a result he says was not picked up by Foundation but was found by a different test. That DNA clue suggests to him that he could try prescribing Herceptin, the breast-cancer drug, even though evidence is limited that it works in salivary-gland cancer. “My next challenge is to get the insurance to agree to pay for these expensive therapies based on rather speculative data,” he says.

Insurance companies may also be unwilling to pay \$5,000 for the pan-cancer test itself, at least initially. Some already balk at paying for well-established tests, says Christopher-Paul Milne, associate director of the Tufts Center for the Study of Drug Development, who calls reimbursement “one of the biggest impediments to personalized medicine.” But Milne predicts that it’s just a matter of time before payers come around as the number of medications targeted to people’s DNA grows. “Once you get 10 drugs that require screening, or to where practitioners wouldn’t think about using a drug without screening first, the floodgates will open,” he says. “Soon, in cancer, this is the way you will do medicine.” 

ADRIENNE BURKE WAS FOUNDING EDITOR OF *GENOME TECHNOLOGY* MAGAZINE AND IS A CONTRIBUTOR TO FORBES.COM AND YAHOO SMALL BUSINESS ADVISOR.

Finding a Solar Solution

Looking to enter a highly competitive solar market, Alta Devices hopes to use a combination of technological advances and manufacturing savvy to succeed where many others have crashed and burned.

By DAVID ROTMAN

Alta Devices is a small but well-funded startup located in the same nondescript Silicon Valley office building that once served as the headquarters for Solyndra, the infamous solar company that went bankrupt last year after burning through hundreds of millions of dollars in public and venture investments. Whether the location has bad karma is still not clear, jokes Alta's CEO, Christopher Norris. But Norris, a former semiconductor-industry executive and venture capitalist, does know that the fate of his company will hinge on its ability to navigate the risky and expensive process of scaling up its novel technology, which he believes could produce power at a price competitive with fossil-fuel plants and far more cheaply than today's solar modules.

On a table in Alta's conference room, Norris lays out samples of the company's solar cells, flexible black patches encapsulated in clear plastic. They look unremarkable, but that's because the key ingredient is all but invisible: microscopically thin sheets of gallium arsenide. The semiconductor is so good at absorbing sunlight and turning it into electricity that one of Alta's devices, containing an active layer of gallium arsenide only a couple of micrometers thick, recently set a record for photovoltaic efficiency. But gallium arsenide is also extremely expensive to use in solar cells, and

thin films of it tend to be fragile and difficult to fabricate. In fact, Alta's innovations lie not in choosing the material—the semiconductor has been used in solar cells on satellites and spacecraft for decades—but in figuring out how to turn it into solar modules cheap enough to be practical for most applications.

The company, which was founded in 2007, is based on the work of two of the world's leading academic researchers in photonic materials. One of them, Eli Yablonovitch, now a professor of electrical engineering at the University of California, Berkeley, developed and patented a technique for creating ultrathin films of gallium arsenide in the 1980s, when he worked at Bell Communications Research. The other, Harry Atwater, a professor of applied physics and materials science at Caltech, is a pioneer in the use of microstructures and nanostructures to improve materials' ability to trap light and convert it into electricity. Andy Rappaport, a venture capitalist at August Capital, teamed up with the two scientists to found Alta, recruiting fellow Silicon Valley veteran Bill Joy as an investor and, with the other cofounders, building a management team that included Norris. The goal: to make highly efficient solar cells, and to make them more cheaply than those based on existing silicon technology.



SUITED UP CEO Christopher Norris holds a gallium arsenide wafer used in making Alta's solar cells. Behind him is a custom-designed reactor used to grow thin layers of the semiconductor.

It is at this point that many solar startups have gone wrong, rushing to scale up an innovative technology before understanding its economics and engineering challenges. Instead, Alta spent its first several years in stealth mode, quietly attempting to figure out, as Norris puts it, whether its process for making gallium arsenide solar cells was more than a “science experiment” and could serve as a viable basis for manufacturing.

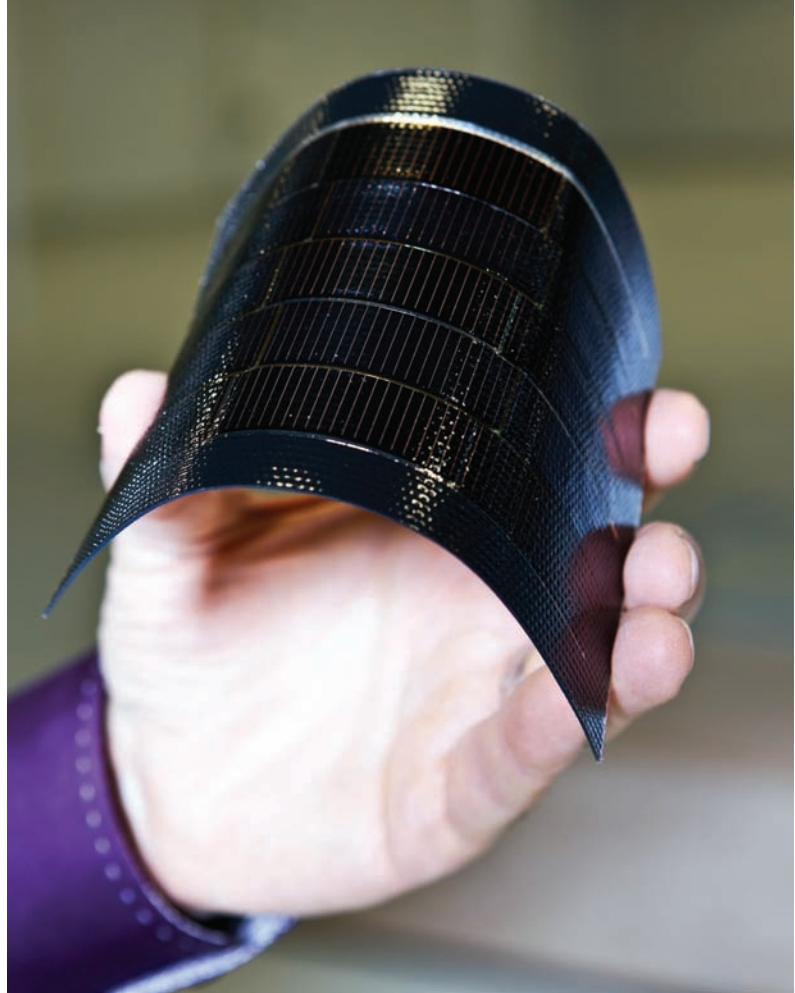
Remnants of the science experiment are still visible in the modest lab at the back of Alta’s offices. Small ceramic pots sit on electric hot plates—relics of the company’s early efforts to optimize Yablonovitch’s technique of “epitaxial liftoff,” which uses acids to precisely separate thin films of gallium arsenide from the wafers on which they are grown. Elsewhere in the lab the equipment gets progressively larger and more sophisticated, reflecting the scaling up of the process. Near a viewing window that allows potential investors to peer into the lab without donning clean-room coverings is one of the jewels of the company’s development efforts: a long piece of equipment in which batches of samples are processed to create the thin-film solar cells. It’s convincing evidence that the early work with pots and hot plates can be transformed into an automated process capable of the yields necessary for real-world manufacturing.

SOLAR LIFTOFF

When Bill Joy, a cofounder of Sun Microsystems and now a leading Silicon Valley venture capitalist, first saw the business plan for what became Alta Devices, he and his colleagues at Kleiner Perkins Caufield & Byers were already looking for high-efficiency thin-film solar technology. Joy keeps a running list—currently about 12 to 15 items long—of desirable technologies that he believes he has “a reasonable chance of finding.” Solar cells that are highly efficient in converting sunlight and that can be made cheaply in flexible sheets could provide ways to dramatically lower the overall costs of solar power. Gallium arsenide technology was a natural choice for efficiency, but Alta’s economics were what really interested the investors. “Their core competency was how to make it manufacturable,” says Joy, who joined Rappaport as an investor within a few months.

Gallium arsenide is a nearly ideal solar material, for a number of reasons. Not only does it absorb far more sunlight than silicon—thin films of it capture as many photons as silicon 100 times thicker—but it’s less sensitive to heat than silicon solar cells, whose performance dramatically declines above 25 °C. And gallium arsenide is better than silicon in retaining its electricity-producing abilities in conditions of relatively low light, such as early in the morning or late in the afternoon.

Key to reducing its manufacturing costs is the technique that Yablonovitch helped figure out decades ago. The semiconductor can be grown epitaxially: when thin layers are chemically deposited on a substrate of single-crystal gallium arsenide, each adopts the same single-crystal structure. Yablonovitch found that if a layer of



FLEXIBLE POWER Alta’s solar cells can be made into bendable sheets. In this sample, a series of solar cells are encapsulated in a roofing material.

aluminum arsenide is sandwiched between the layers, this can be selectively eaten away with an acid, and the gallium arsenide above can be peeled off. It was an elegant and simple way to create thin films of the material. But the process was also problematic: the single-crystal films easily crack and become worthless. In adapting Yablonovitch’s fabrication method, Alta researchers have found ways to create rugged films that aren’t prone to cracking. And not only do the thin films use little of the semiconductor material, but the valuable gallium arsenide substrate can be reused multiple times, helping to make the process affordable.

Research by Alta’s founding scientists has also led to techniques for increasing the performance of the solar cells. Photovoltaics work because the photons they absorb boost the energy levels of electrons in the semiconductor, freeing them up to flow to metal contacts and create a current. But the roaming electrons can be wasted in various ways, such as in heat. In gallium arsenide, however, the freed electrons frequently recombine with positively charged “holes” to re-create photons and start the process over again. Work done by Yablonovitch and Atwater to explain this process has helped Alta design cells to take advantage of this “photon recycling,” providing many chances to recapture photons and turn them into electricity.

Thus Alta’s efficiency record: its cells have converted 28.3 percent of sunlight into electricity, whereas the highest efficiency for a

silicon solar cell is 25 percent, and commonly used thin-film solar materials don't exceed 20 percent. Yablonovitch suggests that Alta has a good chance of eventually breaking 30 percent efficiency and nearing the theoretical limit of 33.4 percent for cells of its type.

The high efficiency, combined with gallium arsenide's ability to perform at relatively high temperatures and in low light, means that the cells can produce two or three times more energy over a year than conventional silicon ones, says Norris. And that, of course, translates directly into lower prices for solar power. Norris says a "not unreasonable expectation" is that the gallium arsenide technology could yield a "levelized cost of energy" (a commonly used industry metric that includes the lifetime costs of building and operating a power plant) of seven cents per kilowatt-hour. At such a price, says Norris, solar would be competitive with fossil fuels, including natural gas; new gas plants generate electricity for around 10 cents per kilowatt-hour. And it would trounce today's solar power, which Norris says costs around 20 cents per kilowatt-hour to generate.

Such numbers are tantalizing. But Norris is quick to bring up another: it costs roughly \$1 billion to build a manufacturing facility capable of producing enough solar modules to generate a gigawatt of power, which is roughly the output of several medium-sized power plants. "I don't see any scenario where we would do this on our own," he says.

GHOST OF SOLYNDRA

Silicon Valley has been infatuated with clean tech since the mid-2000s, but it has yet to figure out something crucial: who will supply all the money necessary to scale up energy technologies and build factories to manufacture them? Venture investors might be skilled at picking technologies, but few of them have the deep pockets or the patience required to compete in a capital-intensive business such as the manufacturing of solar modules. The collapse of Solyndra, which built a \$733 million factory in Fremont, California, is just the most recent reminder of what can go wrong.

Alta's lead investor Andy Rappaport says he usually stays away from investments in clean tech, including photovoltaics. Many investors in solar, he suggests, have bet that a startup could lower the marginal costs of manufacturing and thus "capture some market share." That's "a recipe for failure," he says, because "you need to spend hundreds of millions to build a factory before you know if you have anything of value." The strategy is especially risky now, because photovoltaics are becoming an increasingly competitive commodity business and prices continue to plummet, creating a moving target for new production. But rather than trying to create value by building manufacturing capacity, Rappaport says, Alta can profit from its intellectual property: "We have said simply and consistently that we can scale capacity faster and build a much

stronger company by leveraging partnerships rather than raising and spending our own capital to build factories."

Current investors in Alta include GE, Sumitomo, and Dow Chemical, which recently introduced roofing shingles that incorporate thin-film photovoltaics (see "Can We Build Tomorrow's Breakthroughs?" *January/February 2012*). Though these companies have invested in several rounds of funding—Alta has so far raised \$120 million—eventually Norris would like to see deals, such as licensing agreements or joint ventures, in which manufacturers build capacity to produce Alta's solar cells or use the solar technology in their products. To do that, he says, Alta first needs to "retire the risk" of the production technology, demonstrating to prospective partners that the gallium arsenide solar modules can in fact be produced in an economically competitive way.

POWER NUMBERS

Solar cells vary in how efficiently they convert sunlight

Record solar-cell efficiency (best research cells)	
Gallium arsenide (thin-film)	28.3%
Crystalline silicon	25.0%
Multicrystalline silicon	20.4%
CIGS*	19.6%
Cadmium telluride	16.7%
Dye-sensitized cells	11.0%
Amorphous silicon	10.1%

*Copper indium gallium selenide
Source: Progress in Photovoltaics,
December 29, 2011

Less than a mile from its headquarters, Alta is gutting and renovating a building where Netflix used to warehouse DVDs, turning it into a \$40 million pilot facility to test its equipment. Though the facility is far smaller than a commercial solar factory, it is still no small or inexpensive undertaking. Norris warily eyes the new columns required to reinforce the roof, which will need to hold heavy ventilation and emission-control equipment. But the Alta CEO becomes more buoyant as he approaches the nearly completed back section of the facil-

ity. There, in several white rooms, are the large custom-designed versions of the lab apparatus used to make the solar cells.

Whether Alta succeeds will depend chiefly on how well these manufacturing inventions perform. The cost of the pilot facility might pale next to the price tag for a commercial-scale solar factory, but it is still a critical investment for the startup. And even as Alta is busily trying to get the facility up and running by the end of the year, Norris says, it is taking a deliberate, methodical approach to the process of scaling up. That contrasts sharply with earlier solar startups that spent hundreds of millions in venture investments to build factories as fast as possible. But Alta's cautious approach should not be confused with a lack of ambition. The goal, says Norris, is to make this a "foundational, transformative technology." **tr**

DAVID ROTMAN IS TECHNOLOGY REVIEW'S EDITOR.

Kenya's Mobile Prescription

Local programmers and homegrown business models are helping to realize the vast promise of using phones to improve health care and save lives.

By DAVID TALBOT

Erick Njenga, a 21-year-old college senior wrapping up his business IT degree at Nairobi's Strathmore University, has a gap-toothed grin and a scraggly goatee. A mild-mannered son of auditors, he didn't say much as we tucked into a lunch of grilled steak, rice, and fruit juice at an outdoor café amid the din of the city's awful traffic. But his code had done the talking. Last year Njenga and three classmates developed a program that will let thousands of Kenyan health workers use mobile phones to report and track the spread of diseases in real time—and they'd done it for a tiny fraction of what the government had been on the verge of paying for such an application. Their success—and that of others in the nation's fast-growing startup scene—demonstrates the emergence of a tech-savvy generation able to address Kenya's public-health problems in ways that donors, nongovernmental organizations, and multinational companies alone cannot.

Njenga was humble about the project, but the problem he had tackled was critical in a nation where one in 25 is HIV-positive (10 times the U.S. rate) and AIDS, tuberculosis, and malaria are among the leading killers. In 2010, the Kenyan government realized it had



FREDERIC COURBET/GETTY IMAGES

LIMITED LIFELINE Zuhura Hussein, who does outreach in Nairobi's Kibera slum, has the names of many TB sufferers and HIV-positive clients on her phone but no technology to track them.





to do something about its chaotic system for tracking infectious diseases in order to improve the response to outbreaks and report cases to the World Health Organization. Handwritten reports and text messages describing deaths and new cases of disease would stream in from more than 5,000 clinics around the nation and pivot through more than 100 district offices before being manually entered into a database in Nairobi. The health ministry wanted to let community health workers put information into the database directly from mobile phones, which are ubiquitous in Kenya. The ministry initially sought a solution the usual way: it explored hiring a multinational contractor. It drafted a contract with the Netherlands office of Bharti Airtel, the Indian telecommunications giant that also operates a mobile network in Kenya. The company proposed spending tens of thousands of dollars on mobile phones and SIM cards for the data-gathering task, and it said it would need another \$300,000 to develop the data application on the phones. The total package ran to \$1.9 million.

The contract was never signed; Kenya's attorney general stopped the deal over questions about its reliance on one mobile carrier. Not very many years ago, there wouldn't have been any options within the country. But Kenya's director of public health made an urgent call to Gerald Macharia, the East Africa director for the Clinton Health Access Initiative (CHAI), a wing of the foundation started by former president Bill Clinton. Macharia then called an instruc-

FACE OF AIDS Hussein helps a 48-year-old Kibera resident who needs daily drugs for HIV and tuberculosis. Text-message reminders to take anti-retroviral drugs have been shown elsewhere to help prevent the onset of AIDS and reduce mother-to-infant HIV transmission.

tor at Strathmore, who quickly rounded up the four students. They spent the spring of 2011 at the CHAI offices, receiving internship pay of about \$150 a month. They sat for days with the staff in the health ministry to understand the traditional way of gathering information. Then they pounded out the app and polished up the database software to allow disease reporting from any mobile Web interface. By last summer their "Integrated Disease Surveillance and Response" system was up and running at the ministry, obviating much of Bharti Airtel's proposed costs. The process was "rough—but not too bad," Njenga says. "There were some nights we worked until 2 A.M." He and his colleagues are now finishing an SMS version so that health workers without Web access can make reports via text message from mobile phones of any make or model. The students are also working on another key problem: coming up with ways for the health ministry to track pharmaceuticals it ships to the government's hospitals and clinics, to avoid shortages or waste.

Mobile phones are lifelines for Kenyans. Some 26 million of the nation's 41 million people have phones, and 18 million use them to do their everyday banking and conduct other business; most use a service called M-Pesa, which is offered by the country's dominant

FREDERIC COURRET/GETTY IMAGES

wireless provider, Safaricom. If mobile phones could play as big a role in Kenyan health care as they do in Kenyan financial transactions, the effects could be profound. A growing body of research worldwide is showing that beyond disease surveillance, mobile phones can improve public health by connecting people with doctors for the first time, reminding people to take medications or bring children in for vaccinations, and even enabling doctors in remote areas to view, update, and manage crucial clinical records.

Still, there are big gaps between the promise of mobile health technologies, or “m-health,” and their actual implementation. According to the mHealth Alliance, a Washington-based group, 45 mobile health projects are active or have already been completed in Kenya alone—more than in any other country. Most have been devised and paid for by philanthropies, aid agencies, and NGOs. The projects vary widely: one delivers money via M-Pesa to pay for repair of fistulas, a damaging complication of childbirth; another verifies the authenticity of drugs when workers text their serial numbers. Some have had substantial impact. But most are limited in scope and time frame. And there’s often no business model for sustaining them when the funding runs out, leaving the field suffering from a bad case of “pilotitis,” says Patricia Mechael, executive director of the mHealth Alliance. “The space is incredibly fragmented, unfortunately,” she says. “You have a lot of bits and pieces coming from different angles and lots of pilots going on.”

Meanwhile, IT contracts for government websites, electronic registries, and other large projects are typically conceived by NGOs or donors and carried out by contractors who may be remote from the specific needs of workers at the front lines. “You have people thinking at 30,000 feet: ‘Let’s do websites for every government ministry,’” Jackson Hingu, CHAI’s country director, told me over dinner in Nairobi. That’s good, he says, but it may not meet the needs on the ground: “Have we gone to that pharmacist and asked, ‘Look, what do you do? You are the one who meets the patient and feels the pain.’ Have we understood it thoroughly from that guy’s point of view? Or are we building something so donors can say, ‘Oh, we are online?’” Successful national technology strategies, he argues, require people like the Strathmore students, who have the code-writing chops, can readily work with the people who need to use the technology, and are likely to remain in Kenya to sustain the effort.

THE M-HEALTH GAP

Nairobi’s Prestige Plaza shopping center would look familiar to anyone from a rich country: it’s got an anchor megastore, called Nakumatt, and a food court (the Swahili Plate concession, which dishes up beef stews and curries, is a clue you’re not in Kansas). But one block away, a rutted dirt road perpendicular to the complex leads to the maw of one of Africa’s largest urban slums, Kibera, with 170,000 residents. The outskirts bustle with stalls selling kale, peanuts, sugarcane, herbs, and cell-phone SIM cards. The ground

is hard-packed mud littered with stones and garbage. Single-story huts flank alleyways. Rusty corrugated-metal roofs shed the rains. At the nicer huts, curtains blow through openings. But the smells of smoke and feces linger, and children play near fetid rivulets lined with plastic refuse. The river at the lowest end of the slum becomes like a sewer when it rains. Kibera is, unsurprisingly, a hotbed of infectious disease, including HIV and tuberculosis.

Zuhura Hussein was born in Kibera 38 years ago and never left. (Her roots in Kenya are deep: she is descended from the Nubians conscripted in the Sudan by British colonial forces a century ago and permitted to settle in what was then a lush forest.) A mother of three and grandmother of one, Hussein is one of 140 community health workers attached to one of the clinics that serve the slum. She encourages the people of Kibera to venture out for medical checkups and vaccinations; she also urges patients with HIV or tuberculosis to take their medications every day. She and thousands of Kenyan workers like her are crucial to the success of many global health initiatives, such as the U.S. President’s Emergency Plan for AIDS Relief (PEPFAR), which spends \$500 million per year in Kenya alone.

The day of my visit, Hussein and I snaked through a four-foot-wide alleyway, past two girls peering into a fragment of shattered mirror as they braided their hair next to a pot of boiling meat. We

Mobile phones are lifelines for Kenyans. Some 26 million of the nation’s 41 million people have them. If they could play as big a role in Kenyan health care as they do in Kenyan financial transactions, the effects could be profound.

ducked into one of Kibera’s dim, cramped habitations. When our eyes adjusted, a bed came into focus. A figure wrapped in blankets stirred. The woman (who wasn’t well enough to give permission to use her name) was 48 years old but looked 75. She was HIV-positive and was struggling with a severe case of tuberculosis. “The TB has come back—so many times, I don’t know why,” Hussein said. Asked what she needed, the woman whispered in Swahili: “I want just food—only food.” Amid this scene of despair, a phone rang; Hussein reached into her dress and produced a Nokia model 6070. Later, I scrolled through her contact list and found more than 300 names, from Abdala to Zubeda. Many, she said, were patients she’s worked with.

Phones like Hussein's hold great potential to improve the way health services are delivered. One major study demonstrating as much was started five years ago by Richard Lester, a Canadian infectious-disease specialist. After arriving in Kenya for a research fellowship, noting the ubiquity of mobile phones, and recognizing that the country has only one doctor for each 6,000 citizens, Lester and his team developed a communication link with HIV-positive patients at three health centers, asking them weekly by text message whether they needed any assistance with their antiretroviral drugs (ARVs). Once 500 people were participating, Lester conducted a clinical trial. The results, published in 2010, showed not only that a higher percentage of those receiving the reminders said they took their drugs regularly, but also that viral loads were suppressed in 57 percent of them, compared with only 48 percent of the control group. Today he estimates that expanding that system to all 410,000 Kenyans on ARVs would suppress HIV in 36,000 people, saving \$17.4 million in health-care costs by averting the onset of AIDS or making more expensive drugs unnecessary.

More evidence is streaming in. In western Kenya, a research project called Academic Model for Providing Access to Healthcare (AMPATH), led by the Indiana University School of Medicine and the local Moi University, recently began keeping track of 130,000 HIV-positive patients using electronic health records and automated reminders on Android phones. Now workers in 55 clinics can quickly and easily see what tests or drugs patients need. Published research suggests that the proportion of HIV-positive mothers passing the infection to their babies has dropped below 3 percent, compared with nearly 15 percent in other areas, probably because more of the pregnant women are receiving antiretroviral drugs consistently. "These reminder systems are an extremely important way to make sure all of the *ts* are crossed and better quality of care is provided," says Paul Biondich, a research scientist at Indiana's Regenstrief Institute, who co-developed the underlying open-source records system platform, called OpenMRS.

But all this groundbreaking work is still reaching only a fraction of the people who need help. Sub-Saharan Africa is home to more than two-thirds of the 33 million people estimated to have HIV worldwide. Health IT projects established the usual way—funded by donors or NGOs and run by international contractors—are benefiting relatively few of them, and they are vulnerable to financial cutoffs. Indeed, when Lester's research funding—\$719,000 from PEPFAR—ran out in 2009, two of the three sites he was servicing stopped providing the SMS messages. Lester is now back at his desk at the University of British Columbia, doing what most people do when trying to fix health care in Africa: seeking more grants. "That is the unfortunate fate of the study," he says. "It's been very frustrating to go from research finding to programmatic funding. I think there is an ethical obligation, when you have a clinical trial with positive results, to do everything in our power to provide it as a service."

I had expected that Hussein—a community health worker right in Nairobi, in the heart of a much-studied slum—would have some mobile health technology on her phone. I was mistaken. She can call patients to keep in touch with them, but Hussein had no automated SMS system to remind them to take their drugs. She was not using her Nokia to report any newly discovered disease cases. She received no formal instructions or updates from it. If the phone slips into one of Kibera's ditches, or if Hussein jumps at an NGO's offer for a paid stint of community work (these opportunities sometimes arise



START ME UP Jackie Cheruiyot (left), project leader for a Nairobi startup, tells a Kibera resident about MedAfrica, an app that provides links to doctors, dentists, and first-aid advice. After an investment of less than \$100,000, the app is on 43,000 phones. Doctors are scarce in Kenya, but some people get care from storefront clinics like this one in Narok (right).

only to evaporate after a year or two), the crucial human connection to dozens of people like the patient we called on may be lost.

RISE OF A STARTUP CULTURE

If you travel back up a rutted dirt road from Kibera and turn right on the Ngong Road, just past the Uchumi Hypermarket, you'll see a five-story office building completed in 2009. From the patio ringing the top floor, a haze from diesel fumes and the cooking fires of Kibera's shacks is visible just beyond the crest of a hill. But step inside, and it feels as if you've been transported to a Silicon Valley startup. Dozens of twentysomethings toil away on laptops; a few blow off steam at a foosball table; Pete's coffee bar (not to be confused with Peet's of the United States) doles out cappuccinos, milk shakes, and slabs of banana bread. This is a business incubator called iHub, the fruit of a homegrown infor-

FREDERIC COURRET/GETTY IMAGES



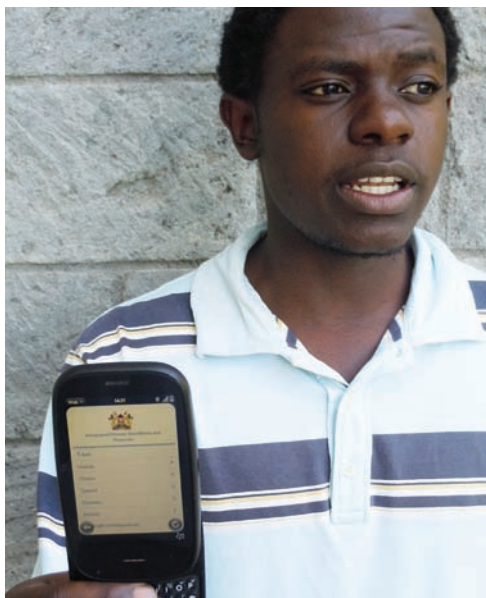
mation technology culture that had its coming-of-age moment in December 2007. That month, ethnic violence broke out after a disputed presidential election; at least 1,100 people died and 300,000 were displaced. Ory Okolloh, a human-rights activist, put out a call to Kenya's loosely knit blogging and technology community to help report on the fighting (see *"Frustrated Innovation,"* p. 11). Several people responded, including Erik Hersman, Juliana Rotich, and David Kobia. In 48 hours, Kobia had written the first draft of an incident-reporting platform called Ushahidi, the Swahili word for "testimony." Now any Kenyan could send in an eyewitness report by text message, and it would be reviewed and then posted on an online map. Ushahidi has since been used widely, in countries including Haiti, South Africa, Russia, and the United States (where it helped map flood-related problems on the Missouri River).

An incident in Ushahidi's formative days planted the seed for iHub. Ushahidi's developers had initially offered the technology free of charge to the Kenya Red Cross Society and other NGOs monitoring the violence. But the NGOs didn't want it; it wasn't part of their existing plans and funding models. "We had so much resistance," Hersman recalls. "We kept trying to say, 'It's free, we will hold your hand, we will help you communicate with the public to say how you are providing a service.' They weren't willing to do anything with it." The experience taught Hersman, 36, that more might get done if local hackers would get together, write more code, and start some companies that had sustainable business mod-

els. He pitched the idea of a corporate-funded space for the tech community to companies including Google and Nokia. "Nobody wanted to set up a hub/lab space in Africa," he says. "That sounded crazy in 2008." Finally, the Omidyar Network, the philanthropy founded by eBay founder Pierre Omidyar, donated \$200,000 to fund iHub for two years. Other donors, including Nokia, Google, and the African ISP Wananchi, stepped up with equipment and high-speed Internet service.

The incubator opened in 2010 and now counts more than 6,000 members, with an average of 1,000 new applications a year. Most members are merely part of iHub's online community, but more than 250 of them use the space. Some 40 companies have launched from iHub, and 10 have received seed funding from venture capitalists. The most successful so far is Kopo Kopo, which helps merchants manage payments from M-Pesa and similar services. One key to iHub's growth is that Kenya's IT infrastructure has improved significantly. The first Internet fiber connection landed at the Kenyan coast in 2009 (previous service had come through satellite dishes in the Rift Valley), and the country's first truly mass-market Android smart phone went on sale in 2010, for \$80. Safaricom now counts 600,000 smart phones of all kinds on its network and expects them to make up 80 percent of the market by 2014.

Inevitably, this petri dish produced a mobile health startup. Shimba Technologies, led by a couple of University of Nairobi graduates named Steve Mutinda Kyalo and Keziah Mumo, cre-



APP FOR THAT Mark Ekisa, a Strathmore University student, shows off an interface for the new mobile and Web-based disease reporting system he helped create. Tech-savvy graduates fill the offices of iHub (center), a startup incubator founded by Erik Hersman (far right), one of the creators of the Ushahidi incident-reporting platform now in use around the world.

ated a platform called MedAfrica with the simple goal of providing basic health information to Kenyans in the face of the national doctor shortage. So far, MedAfrica offers lists of doctors and dentists taken from government registries, plus menus for finding basic first-aid and diagnostic information. “What we want is for the common man to have the right information in his hand,” says Kyalo, the company’s CEO. “We can’t replace the doctors, can’t replace the hospitals, but we can improve access to relevant information.”

MedAfrica illustrates the power of local entrepreneurship. Though it has few connections with the medical community or the health ministry, its health-care app has been downloaded on 43,000 phones, and the company is still only halfway through \$100,000 in seed funding. The service can be delivered through an app or through a mobile Web interface (nearly all Kenyans who access the Internet do so through mobile devices). Soon it will be available through SMS—an essential feature, because 85 percent of Kenyan mobile-phone owners don’t yet have Web access. Kyalo hopes to aggregate other medical apps on the platform and ultimately sell sponsored messages from pharmaceutical companies, health-care providers, and others.

I joined Kyalo and one of his colleagues, Jackie Cheruiyot, a leukemia survivor who has firsthand experience with the scarcity of Kenyan health services, as they hit the road to pitch the app to potential users. They faced skepticism as they made cold calls in Narok, two hours west of Nairobi. In Narok’s bustling downtown, with a mosque at its center, women picked over vegetables and potatoes while men hauled sacks of grain on carts or peddled small red sausages; a three-man team dug out a culvert to clear

green water from a roadside ditch. At the Narok District Hospital, a government-run facility festooned with posters and stickers from the U.S. Agency for International Development, the Centers for Disease Control, and other donor groups, Cheruiyot knocked on the door of the head nursing administrator, disarmingly singing out “Welcome!” But the administrator shooed us away with this reproach: “You must get authorization from the health ministry.” The idea of a startup company trying to participate in health care is still far too alien. “Government is the hardest nut to crack,” Kyalo said as we beat our retreat.

Other startups have emerged without iHub’s help. Changamka Microhealth sells health payment cards that can be charged up through M-Pesa. You buy a card, preloaded with 450 shillings, for 500 shillings—Changamka makes 50 shillings, or about 60 cents, on each—and then you make M-Pesa payments to add money until you’ve got enough for a given procedure. (There’s even a special card for pregnant women; a hospital childbirth costs about 4,000 shillings, or \$50, a sum many cannot easily or safely save at home.) And Intellisoft Consulting builds electronic medical records platforms, which many clinics throughout Kenya employ. It provides this infrastructure using OpenMRS, the open-source platform initially developed by Indiana University researchers and the NGO Partners in Health, which continues to evolve with help from dozens of developers, many of them Kenyans. Such companies are developing a crucial local capacity to improve health care, says Paul Biondich, the Indiana University researcher. “We have to do things like iHub, help the local people get organized, and set up a way that the cash coming in to support health is increasingly available to these kinds of startup entities,” he says.

FROM M-PESA TO M-HEALTH

Larger Kenyan companies are starting to figure out how to do that—using the promising ideas and developing business models from

DAVID TALBOT (LEFT); FREDERIC COURBET/GETTY IMAGES



them. On the same day Kyalo launched MedAfrica last November—with doctors' phone numbers as a major selling point—Safaricom announced that it was launching its own doctor-calling service. In a nation with few doctors and no free 911 service for medical emergencies, residents can now at least speak to a doctor for about 25 cents per minute. The service already fields 500 calls per day, but while it's helping, it also painfully illustrates the challenges facing its potential users. Nzioka Waita, Safaricom's director of corporate responsibility, described a call that came through in January from a woman desperate for help because her husband wouldn't wake up. During the course of the call, her mobile-phone credits ran out, though the doctor was able to call her back. Safaricom says it is in discussions with a partner willing to subsidize future emergency calls so they can't be cut off.

Safaricom is also working with partner companies to do for health care what it did for banking with M-Pesa. A system now being designed—initially for pregnant women in several rural districts—would let community health workers create an electronic medical record for each patient, update the records, and send health information and reminders to the patients' phones. In many ways, the project would adapt technologies pioneered by groups like AMPATH and allow them to be rapidly scaled up.

The \$2.3 million project is expected to roll out this spring. The idea is for community workers, armed with a phone and sheets of ID cards bearing bar codes, to issue a card to a woman and scan the code with the phone's camera, registering the woman's identity. The woman, if she has a phone, would then receive text messages offering health advice and reminders of upcoming appointments. On each return visit, new information, tied to the bar-code identifier, would be uploaded by SMS to a central database. Crucially, the system would build on existing mobile billing and banking platforms. Each transaction uses phone minutes, which are mostly prepaid in Kenya and could be subsidized by donors.

And in a nation where 75 percent of the population is not covered by any health insurance, Safaricom envisions enrolling people in insurance programs and letting them make payments via M-Pesa. About 50,000 laborers have recently started doing just that. Handling the financial side of health care with mobile phones, say Biondich and others, would make it possible to bring more people into the system and thus improve the nation's health. Mobile payment also provides a potentially efficient way for donors to fund health care.

Nairobi's Kenyatta National Hospital, one of the largest hospitals in sub-Saharan Africa, has a distinctly 1930s feel, with painted wooden doors and hand-painted signs. One day Ambrose Kwale, the hospital's director of IT, showed me around. There was a new 25-bed isolation unit for multiple-drug-resistant tuberculosis, and a grassy spot outdoors where several people who appeared to be in their 50s or 60s were sprawled, some curled in the fetal position. These were cancer patients. Many had traveled overnight, referrals in hand, for appointments with some of the few oncologists in East Africa. (One hospital IT initiative is to install a telemedicine facility to help patients at regional medical centers avoid the trip to Nairobi to see specialists.) A woman who appeared to be in her 30s, wearing a pink jacket and a flowered shawl, leaned against a concrete pillar, short of breath. When Kwale approached, she weakly handed him a piece of paper marked up in blue pen. She had traveled 50 kilometers to see a specialist for her breast cancer, and now she was alone, exhausted, and at the wrong place on the campus. A pale blue cataract blighted her left eye, and a look of fear and pain shadowed her face as she rested her head against the pillar. Kwale could only call for an orderly to help the woman find her way.

Mobile technologies offer great potential to help patients like her—to keep track of their care, provide reminders, and give them broader access to expertise. And experience is showing that local talent can create the technology.

The challenge lies in organizing this emerging talent so that it can tackle large-scale projects. Last year USAID, a major funder of health projects in Kenya and other developing countries, requested proposals for help creating a unified, Web-based national health information system that would be "host country owned." The five-year, \$32 million contract went to Abt Associates, a consultancy based in Cambridge, Massachusetts, which has done extensive work in global development projects. But although it has expertise, so does the new tech class back in the host country—which also has a long-term stake in the solution and no U.S. overhead. "If you talked about an RFP for \$32 million at iHub, people would go nuts! You'd fund 500 startups for that," CHAI's Jackson Hungu says. "And this country's public health delivery would be changed forever. I have no doubt about that." **tr**

DAVID TALBOT IS *TECHNOLOGY REVIEW*'S CHIEF CORRESPONDENT.

The Patient of the Future

Internet pioneer Larry Smarr's quest to quantify everything about his health led him to a startling discovery, an unusual partnership with his doctor, and more control over his life.

By JON COHEN

Back in 2000, when Larry Smarr left his job as head of a celebrated supercomputer center in Illinois to start a new institute at the University of California, San Diego, and the University of California, Irvine, he rarely paid attention to his bathroom scale. He regularly drank Coke, added sugar to his coffee, and enjoyed Big Mac Combo Meals with his kids at McDonald's. Exercise consisted of an occasional hike or a ride on a stationary bike. "In Illinois they said, 'We know what's going to happen when you go out to California. You're going to start eating organic food and get a blonde trainer and get a hot tub,'" recalls Smarr, who laughed off the predictions. "Of course, I did all three."

Smarr, who directs the California Institute for Telecommunications and Information Technology in La Jolla, dropped from 205 to 184 pounds and is now a fit 63-year-old. But his transformation transcends his regular exercise program and carefully managed diet: he has become a poster man for the medical strategy of the future. Over the past decade, he has gathered as much data as he can about his body and then used that information to improve his health. And he has accomplished something that few people at the forefront of the "quantified self" movement have had the opportunity to do: he helped diagnose the emergence of a chronic disease in his body.

Like many "self-quanter," Smarr wears a Fitbit to count his every step, a Zeo to track his sleep patterns, and a Polar WearLink that lets him regulate his maximum heart rate during exercise. He paid 23andMe to analyze his DNA for disease susceptibility. He regularly uses a service provided by Your Future Health to have

blood and stool samples analyzed for biochemicals that most interest him. But a critical skill separates Smarr from the growing pack of digitized patients who show up at the doctor's office with megabytes of their own biofluctuations: he has an extraordinary ability to fish signal from noise in complex data sets.

On top of his pioneering computer science work—he advocated for the adoption of ARPAnet, an early version of the Internet, and students at his University of Illinois center developed Mosaic, the first widely used browser—Smarr spent 25 years as an astrophysicist focused on relativity theory. That gave him the expertise to chart several of his biomarkers over time and then overlay the longitudinal graphs to monitor everything from the immune status of his gut and blood to the function of his heart and the thickness of his arteries. His meticulously collected and organized data helped doctors discover that he has Crohn's, an inflammatory bowel disease.

I have ulcerative colitis, a cousin of Crohn's, and I am intrigued by what Smarr calls his "detective story." His investigation of his body has evolved into a novel collaboration with a leading gastroenterologist to better understand and treat his disease, and maybe even to help others like me. But I am also a disease-weary skeptic. After 22 years of seeing specialists, enduring a battery of tests, unscrambling the complex medical literature, and trying a hodgepodge of interventions, I have had no luck staving off flares and only modest success controlling them with blunt-force drugs. Like others who have chronic illnesses, I am acutely sensitive to false hope. I have been repeatedly baffled by the course my disease takes and thoroughly confused by tests meant to clarify my condition.

GYM RAT In his quest to optimize his health, Larry Smarr recently underwent tests to measure his peak oxygen consumption, maximum heart rate, and other physiological indicators.



When I first meet Smarr and he gives me a tour of his institute, commonly known as Calit2, I tell him that I find it difficult to separate promise from hype, noting that his endeavor has all the pitfalls of any “ $n = 1$ ” experiment—a test in which only one person is the subject. “Every disruption begins with an n of 1,” he replies.

Smarr has a standard-issue office on the side of a sleek six-story building, but much of his floor resembles a hip architectural firm. Workstations zigzag across a vast space that features exposed venting pipes and electrical conduits on the naked ceiling. His chief assistant, who lives near San Francisco, talks to coworkers via Skype and a dedicated computer monitor. Across the room, chairs are arranged before a wall of 30-inch displays stacked five high and 14 wide, with a total of 286.7 million pixels that can simultaneously show dozens of brain scans or the stars in a galaxy.

Though he has no laboratory of his own, he shows off the projects at Calit2 as though each were one of his children. The labs investigate everything from machine perception and game culture to integrated nanosensors and 3-D virtual reality. One, which Smarr recently tapped to determine his peak oxygen consumption and maximum heart rate, studies ways to improve individual and population health. Another researches digitally enabled genomic medicine—a blend of self-quantification devices with wireless technology and DNA data.

The place makes my imagination dance. So, too, does Smarr’s medical sleuthing of his own body. Not only does he want to convince others that they can fundamentally alter the patient-doctor relationship and transform physicians into partners, but he’s also going public with his biodata, hoping to crowdsource information that will lead to new insights about the elusive links between DNA sequences, biomarkers, and disease. I soon buy into his vision, embarking on a closer examination of my own disease that, at the very least, scuttles my resignation to it.

MYSTERY SOLVED

Larry Smarr stumbled into his role as a proselytizer for digitizing and then crowdsourcing medicine; he stresses that by nature he is a reserved and private person. He was born and raised in Columbia, Missouri, where his parents ran a flower shop from the home basement. One of his greatest passions is the quiet, solitary cultivation of that most finicky and delicate of plants, the orchid. Yet he has no regrets about going public in writings and talks with extremely intimate details about his body. “Most people think I’m crazy,” he says. But as a result of his candor, many people have contacted him, he says, and he shows me how a Google search on his name now pulls up articles about his quantified-health quest before everything else he has published in his distinguished career.

Smarr says he “got outed as a quantified self” after he spoke at a technology summit in May 2010. A session titled “BioNanoInfo Technology: The Big Challenges” featured him on a panel with

Leroy Hood, a cofounder of the Institute for Systems Biology in Seattle and one of the inventors of the first automated DNA sequencer. Hood discussed his push for technology that he hopes will introduce an era of medicine he calls P4: predictive, preventive, personalized, and participatory. Smarr told his own story of using self-quantification to lose weight. A reporter interviewed him after the session, seeking more details, and in the wake of that article, speaking requests started to pour in.

Hood envisions a day when devices using nanotechnology will measure 2,500 markers in blood to track fluctuations in what he estimates are about 50 proteins in 50 of the body’s organs. But that is not yet practical, so Smarr settled on about 100 biomarkers to understand how his dietary changes were affecting his body. Levels of one of the markers, C-reactive protein, or CRP, stood out as higher than normal.

CRP triggers an immune response by binding to the surface of ailing cells, and the level of it should be less than one milligram per liter of blood. Smarr’s level in November 2007 was 6.1. More alarming still, over the next seven months it steadily climbed to 11.8. He felt fine, but he decided to seek a doctor’s advice, worried that something was amiss. The doctor dismissed Smarr’s self-charted longitudinal CRP data, telling him to return if he had symptoms. “Doctors are the gatekeepers, and they’re worried about getting disintermediated,” he says, comparing them to the bank tellers who initially bad-mouthed ATMs.

Within a few months, a sharp, persistent pain in the left side of his abdomen sent him to the doctor’s office, and he was diagnosed with acute diverticulitis, an infection of pockets in the wall of the colon. A blood test showed that his CRP had climbed to 14.5 during the attack. He took antibiotics, the symptoms resolved, and his CRP dropped to 4.9—but that was still unusually high. Concerned that these readings might, as he had read, indicate a plaque buildup that could lead to a heart attack, he had doctors do ultrasounds of his carotid artery and found that it was indeed thickening.

To better understand the attack, he had his stool analyzed for, among other things, lactoferrin, a marker of inflammation. His lactoferrin, too, rose several times to sky-high levels—200, whereas the normal count is less than 7.3. When he overlaid his results on a graph with his CRP fluctuations, he noticed that the two roller-coasted in tandem. A colonoscopy in December 2010 revealed extensive diverticulitis, but Smarr, who had trolled the medical literature online, remained unconvinced that this was his underlying disorder. He became particularly intrigued by studies that linked high lactoferrin levels to inflammatory bowel disease.

At this point, Smarr discovered that UCSD had recently hired a new head of gastroenterology, William Sandborn, who had published a compelling study that charted rises in lactoferrin levels during flares of inflammatory bowel disease. The two met and decided to do yet another colonoscopy. By then, Smarr’s lactoferrin level

Not only does Smarr want to convince others that they can fundamentally alter the patient-doctor relationship and transform physicians into partners, but he's also going public with his biodata.

had risen to a whopping 900. Sandborn reviewed the results and concluded that his new patient might have Crohn's disease. Smarr now thinks his diverticulitis attack was actually a Crohn's flare.

"It's a paradigm for what will happen in the future," Hood says of Smarr's story. "With P4 medicine, consumers are going to be the driving force—it isn't going to be physicians. They're going to demand to quantize themselves about their own wellness and what can be done."

Cardiologist Eric Topol, author of *The Creative Destruction of Medicine* (see "Technological Healing," January/February 2012) and head of the Scripps Translational Science Institute down the street from UCSD, supports the self-quantification movement but says it has the most to offer people who, like Smarr, zoom in on specific issues. "My colleagues have a doctors-know-best attitude," says Topol. "Individuals like Larry have much more invested here, and they're going to put in time and resources to gather as much information as possible. Those clinicians who have the plasticity to adapt to this will be better doctors in the future."

Smarr recognizes that many people do not have his skills at amassing and analyzing data, nor do they have his resources—he estimates that his "burn rate" for tests and other expenses his health insurance would not pay for has ranged from \$5,000 to \$10,000 per year. Still, he thinks medical quests like his will become more common with the emergence of technologies that more easily and cheaply test biomarkers and sequence DNA. "My particular story is a good example of an early victory," he says. "I'm not saying we need to get rid of doctors. But imagine if you go in to the doctor and little widgets have been recording data to the cloud and the doctor can look at it. That's going to be a vastly more productive visit. There'll be a liberating effect on them."

GUT CHECK

Unlike the doctors who deemed Smarr's data mining a clinically useless "academic" exercise by an amateur, Sandborn welcomes his input. "I've learned an enormous amount from listening to patients over the years and just being open-minded about the journey that they go through with their illness," says the gastroenterologist. Yet Smarr's unusual project and personality have clearly encouraged Sandborn to explore a patient-doctor relationship of a kind he might have avoided with others. Sandborn notes that in many

cases, overtesting wastes money, sends patients on tangents, and can lead to false positive results that actually cause harm. "None of those things apply in Larry's case," he says.

Sandborn has agreed to accompany Smarr on an expedition into another medical frontier: the microbiome. In 2010, *Nature* published a study that sifted through fecal samples from 124 people, plucking out the microbial genes in healthy individuals and those with Crohn's or ulcerative colitis. In the healthy group, the researchers found an average of 3.3 million microbial genes—about 150 times the number of genes in the human genome. People who had an inflammatory bowel disease harbored 25 percent fewer microbial genes, and the species of bacteria that were depleted differed in people with Crohn's and those with ulcerative colitis.

Smarr being Smarr, he decided to have his microbiome sequenced at the J. Craig Venter Institute. Sandborn, in turn, plans to work with researchers at the Venter Institute to assess whether they can pull something meaningful out of this most basic data, coupled with Smarr's biomarkers and the evolution of his disease. Future treatments, for example, might specifically repopulate the gut with the bacteria that people with the disease are lacking. Smarr also plans to have his entire genome sequenced by George Church, the Harvard University geneticist whose Personal Genome Project recruits people willing to share medical records and DNA sequences. "Larry and a few others are becoming very well-measured individuals," says Church. "What we're trying to do is gather together such individuals and turn it into more of a collective process. If you keep data to yourself, it's hard to interpret."

Larry Smarr has not convinced me that I can manage my ulcerative colitis more effectively by following his lead. But his experience has prodded me to consider options I previously discounted or didn't know about. I had 23andMe analyze my single-nucleotide polymorphisms, which spotlighted a mutant immune-system gene I carry that almost doubles my risk for ulcerative colitis. I joined the Personal Genome Project—which will also sequence my microbiome—and agreed to make all my DNA and medical records public. I saw Sandborn as a patient, and we plan to monitor my CRP and lactoferrin during a flare and on medication. If I can find immune-modulating drugs on the market that specifically counteract the effects of my mutant gene and do not have serious side effects, Sandborn says, he's willing to try those on me too.

At the end of my consultation with Sandborn, it becomes clear that we share a sense of skepticism and hope about the new medical world that Larry Smarr has encouraged each of us to enter. "I have no doubt this is the future of medicine, but I have no idea how to get there from here," he says. "Then again, when you find the right patients, you can start to figure out how to move forward." **tr**

TR CONTRIBUTING EDITOR JON COHEN IS A CORRESPONDENT WITH SCIENCE. HIS LATEST BOOK IS *ALMOST CHIMPANZEE: REDRAWING THE LINES THAT SEPARATE US FROM THEM*.

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HOW TECHNOLOGY IS CHANGING BUSINESS

They grew up with the Web—now they're disrupting it. In this issue and online, *Technology Review* explores the world of the twenty-somethings who are redefining technology business models.



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The Youth Effect

THE BIG QUESTION

Innovation Without Age Limits

Young stars dominate the technology headlines. But outside the Internet, research shows, innovators are actually getting older as complexity rises.

By VIVEK WADHWA

Venture capitalists in Silicon Valley prefer to fund the young, the next Mark Zuckerberg. Why? The common mantra is that if you are over 35, you are too old to innovate. In fact, there is an evolving profile of the “perfect” entrepreneur—smart enough to get into Harvard or Stanford and savvy enough to drop out. Some prominent figures are even urging talented young people to skip college, presumably so they do not waste their youth on studying.

To a degree, the cult Silicon Valley has built around young people makes sense—particularly in the Internet and mobile technology. The young have a huge advantage because they aren’t encumbered by the past. Older technology workers are experts in building and maintaining systems in old computer languages and architectures. They make much bigger salaries. Why should employers pay \$150,000 for a worker with 20 years of irrelevant experience when they can hire a fresh college graduate for \$60,000? After all, the graduate will bring in new ideas and doesn’t have to go home early to a family.

These graduates grew up in an era when the whole world was becoming connected. To them, the world is one giant social network in which they can play games or work with anyone, anywhere. This is not a U.S.-only phenomenon. Children in Egypt and China are as Web-savvy as Americans. With better, more timely information at their fingertips than any generation has had in history, the world’s children can rise above the fears and biases of their parents. That is why youth in the Middle East are fomenting revolutions and the Chinese are getting restless. A key ingredient in innovation is the ability

to challenge authority and break rules, a passion the Internet is unlocking among a new generation of youth worldwide.

The young understand the limits of the Web world, but they don’t know their own limits. Since they don’t know what isn’t possible, the Zuckerbergs can come up with new solutions to old problems. That is why

they lead the charge in starting innovative mobile and Web companies.

But great ideas by themselves don’t lead to breakthrough technologies or successful companies. Ideas are a dime a dozen. The value comes from translating ideas into inventions and inventions into successful ventures. To do this, you have to collaborate with others, obtain financing, understand markets, price products, develop distribution channels, and deal with rejection and failure. In other words, you need business and management skills *and maturity*. These come with education, experience, and age.

Indeed, research by my team revealed that the average and median age of the founders of *successful* U.S. technology businesses (with real revenues) is 39. We found twice as many successful founders over 50 as under 25, and twice as many over 60 as under 20. So everyone has a shot at success, but it seems age provides a distinct advantage.

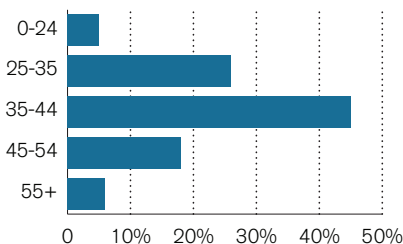
Are venture capitalists misguided, then, in funding companies with baby-faced CEOs? Perhaps one answer lies in the results of a study conducted by the Kauffman Foundation. It found that during the period when funding young technology entrepreneurs became the norm, from 1997 to 2007, the venture industry grew dramatically. But returns actually stagnated and then declined sharply. The returns of the venture industry lagged those of the small-cap Russell 2000 Index by 10 percent over the 10-year time frame.

When you meet entrepreneurs in India, Ireland, Brazil, and other parts of the world, you find many of the same dynamics at play. The young have the outrageous ideas, but it’s older people who achieve business success. In all these countries, youth entrepreneurship is on the rise. And as in the United States, most of these businesses fail. That’s okay when you can learn from your failures and start over—again and again. This has been Silicon Valley’s advantage: it accepts failure and encourages entrepreneurs to keep trying. It hasn’t been like this in other

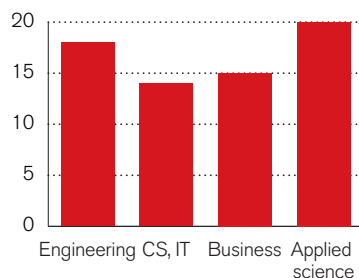
TIME FOR ENTREPRENEURSHIP

A survey of entrepreneurs found that the average age at which they started their first company was 39. Those with computer science training started companies sooner than those in other fields.

Age of U.S.-born tech founders at time of company founding



Years between last academic degree and company founding, by field of study



Source: “Education and Tech Entrepreneurship,” Kauffman Foundation, 2008

parts of the country and the world. In most places, if you fail, you don't get a second chance. But cultures are changing. They are beginning to accept failure. So entrepreneurs all over the world are trying again and again. In the process, they are getting older and smarter, and eventually achieving success.

Most of what I discussed above was in the computing world. But today other fields of science and engineering, such as robotics, synthetic biology, medicine, and nanomaterials, are experiencing growth as dramatic as the expansion that Moore's Law describes for computing power. The human genome, for example, was first sequenced about a decade ago at a cost of more than a billion dollars; now the same feat costs a few thousand dollars. Together, all these advances are making it possible to address many of the grand challenges of humanity: making sure we all have adequate education, water, food, shelter, health, and security. Entrepreneurs can now do what only governments and large corporations were once capable of.

But understanding these diverse technologies isn't the domain of the young. Though college dropouts may know all about social media, it is very unlikely that they understand the intricacies of nanotechnology and artificial intelligence as well as their elders do. These are complex technologies that require not only a strong education but also the ability to work across domains and collaborate with intellectual peers in different disciplines of science and engineering.

Given all the new complexities in the sciences, it is no surprise that innovators are actually getting older.

Kellogg School of Management economist Benjamin F. Jones analyzed the backgrounds of Nobel Prize winners and other great inventors of the 20th century. He found that the average age at which they made their greatest innovations was 39. The largest mass of great advances, 72 percent, came in an inventor's 30s and 40s, and

only 7 percent came before the age of 26. What's more, Jones found that the age at greatest achievement is actually rising, by about six years over the last century. Indeed, that effect was due to *decreasing* rates of invention at younger ages. The explanation is probably simple. People are spending more time in training as a prerequisite to contribute to complex fields.

The reality is that there is no age requirement for innovation. The young and old can

both innovate. The young dominate new-era software development, and software will be a key driving force in the convergence of other technologies that are expanding exponentially. So we badly need our young. And we need our older entrepreneurs to develop cross-disciplinary solutions that solve the grand challenges of humanity. **B**

VIVEK WADHWA IS VICE PRESIDENT OF ACADEMICS AND INNOVATION AT SINGULARITY UNIVERSITY AND HAS AFFILIATIONS AT DUKE, STANFORD, AND EMORY. HE IS 54 YEARS OLD.

CASE STUDIES

Too Young to Fail

At 17, Laura Deming doesn't drive and can't vote. Is now her chance to change the world?

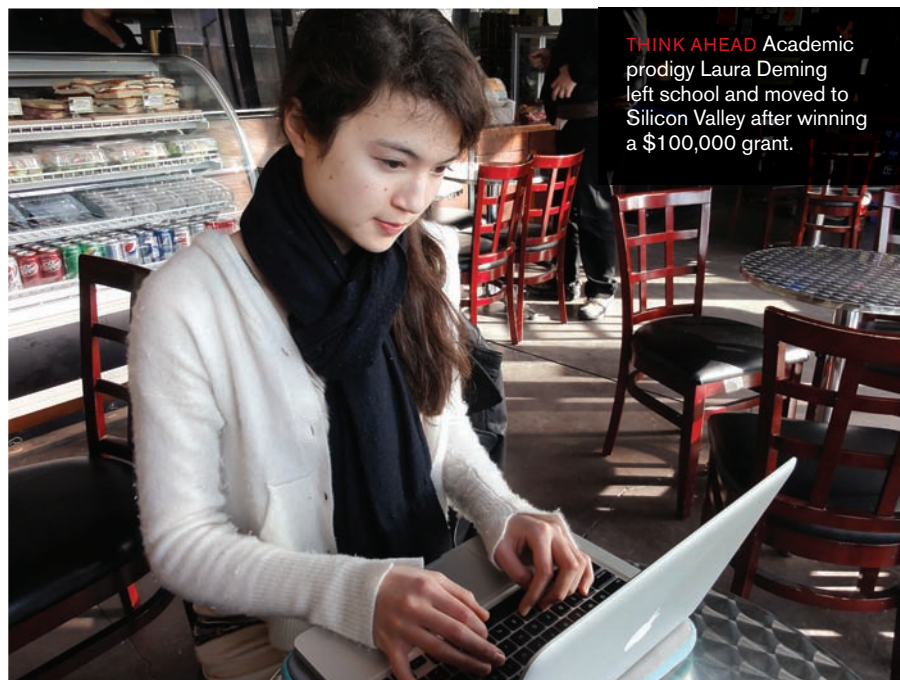
By JESSICA LEBER

Laura Deming was studying for finals in a crowded MIT reading room last April when her phone rang. That's when she learned she may never take another exam.

Deming, only 17, had just been chosen by Silicon Valley billionaire Peter Thiel for a high-profile experiment: put \$100,000 apiece in the hands of 24 entrepreneurial teenagers and give them free rein to pursue innovative ideas. The condition? Deming had to leave her studies and classmates, and

vow to stay out of college during the two-year fellowship.

Thiel, who is PayPal's cofounder and holds two Stanford University degrees, says a "crazy bubble" in higher education has the effect, like a bad mortgage, of saddling students with debt for too little in return. A vocal libertarian, Thiel, 44, takes the view that a college degree can be harmful to innovators because of the conservative, career-driven mind-set it imparts.



THINK AHEAD Academic prodigy Laura Deming left school and moved to Silicon Valley after winning a \$100,000 grant.

"Youth have just as much intelligence and talent as older people," says James O'Neill, head of the Thiel Foundation and managing director at Thiel's investment fund, Clarium Capital. "They also haven't been beaten down into submission by operating within an institution for a long time."

Not every young person is like Deming, a home-schooled prodigy who learned calculus at 11 and sought experience in a cutting-edge genetics lab at 12. That's where she first explored the science of extending human life span, an idea she hopes to turn into a business. For Deming's cohort, chosen from more than 400 applicants, Thiel's endorsement has been followed by some quick successes. Eden Full, 19, won a \$260,000 award for her efforts to improve solar energy in developing countries. Dale Stephens, 20, landed a deal with Penguin for his book *Hacking Your Education*.

Still, the foundation embraces the startup ethic that failure is inevitable, even desirable. So does John Deming, Laura's father, an investor who moved the family to Boston when his daughter enrolled at MIT at age 14: "What I say to Laura is, 'The biggest problem you have so far, kid, is you haven't failed yet.'"

After packing up her things at Sigma Kappa sorority, Deming moved across the country to a tiny room in a shared house in Palo Alto. Most days, she rises before dawn and heads out on foot to catch a commuter train to San Francisco, where she is talking to investors about a venture capital firm she wants to create to back research on new therapies for age-related diseases.

Because of SEC rules, Deming says, she can't go into details. But she jokes that one question now is whether to wait until her 18th birthday so that she can legally sign up investors or ask her father to do it. "The cool thing about Silicon Valley is that though people might be skeptical of youth, they don't actually know that you're not smart enough or capable enough to make it work," she says.

With success stories tempting undergraduates to quit, a number of universi-

ties have raced to add entrepreneurship to their curricula. Stanford has StartX, an accelerator for student-run startups, and last year UC Berkeley created Founder-School, which prepares students to raise venture money. James G. Boyle, managing director of the Entrepreneurial Institute at Yale University (which lost four undergraduates to Thiel fellowships), says that most students benefit from an environ-

ment where they can test ideas without betting their future.

Deming doesn't know yet whether she'll ever finish her degree. "The funny part is I think I'll miss studying for exams," she says. "It's the sort of thing that was very fun—like a sudoku puzzle or a crossword puzzle can be fun. But I thought that I could learn a lot more about the biotech industry and business by diving right into it." **BI**

LEADERS

Venture Capital, Disrupted

For a new generation of technology company founders, money is the easy part.

By TOM SIMONITE

Silicon Valley's venture capitalists make their money by funding ideas that disrupt established industries. But these gatekeepers are now being challenged themselves.

A fast and furious new funding model is funneling money to young company founders, asking relatively little in return. Startup-incubator programs—Y Combinator is the most prominent—now put founders through a kind of tech-industry boot camp in exchange for a small stake in their company. For many, the next stop is AngelList, a social network for angel investors and entrepreneurs where young people can shop for financing without spending years developing contacts in the old-boy network of venture capital. AngelList's cofounder Naval Ravikant explained to *Technology Review's* IT editor Tom Simonite how the next generation of Silicon Valley CEOs is getting a business education on the fly.

TR: What are you trying to do with AngelList?

Ravikant: We're trying to democratize access to capital and bring the Silicon Valley ecosystem online. It shouldn't be about who you know. It shouldn't be a painful one- or two-year process building connec-



ANGEL FIRE Investor Naval Ravikant launched a social network for startups to raise money.

tions, contacts, and credibility. Rather, you should be able to take your work, throw it out there for the world to see and decide if it's great. Investors should be able to find you. We have 20,000 startup profiles on the site, and one or two raise money every day.

Many of the most talked-about companies in Silicon Valley came out of incubators. Why have these been so successful at attracting entrepreneurs?

The cost of building a company has collapsed. Now your average 22-year-old can start a company without much money, just some time and effort. But you also need

to know how to set up a company, how to find investors, how to recruit, to know best practices and design. I look at incubators as sort of a very quick vocational school.

Are founders of technology startups getting younger as a result?

Yes. They were always capable of it, there's no magic, but now they have the means and the tools. Almost all the great companies were started by very inexperienced entrepreneurs—Steve Jobs, Larry Ellison, and Bill Gates. A lot of these people coming out of college are actually fully capable of being entrepreneurs; they just need that last little bit of vocational training.

What about business school?

I think incubators are just replacing it wholesale. The theory was you go to business school to learn entrepreneurship. But the reality is they're going to spend two years and \$200,000 learning from some guy who's never started a company in his life. Things move very, very quickly today. At an incubator, you're going to learn fast in a community of your peers in an environment where there's pressure on deliverables and shipping schedules.

Longer term, will these young founders become the new venture capitalists?

That's already happening. As they make money as they're younger and younger, you will have younger VCs and younger people with broad relationship networks. They don't want to go join some bigger, old VC firm. They want to do their own thing. The so-called super-angel or seed funds—many of them are started by people who were a little young to be in a traditional VC crowd.

Is there an unsustainable bubble of young founders and companies?

The number of competitors has gone up so much that it suddenly looks very crowded. Some people are saying that there's a lot of noise and a lot of them are going to fail. But the cost of failure is incredibly low, so what do they lose? They just go get another job or start another company. **B**



TOP CODER Facebook CEO Mark Zuckerberg checks in with programmers during a hackathon.

EMERGED TECHNOLOGIES

Letting Hackers Compete, Facebook Eyes New Talent

The social network puts engineers, not HR, in charge of a global search for young programmers.

By TOM SIMONITE

Late this January, some 75,000 people around the planet sat in front of their computers and pondered how to make anagrams from a bowl of alphabet soup. They were participants in the Hacker Cup, an international programming battle that Facebook organized to help it find the brightest young software engineers before competitors like Google do.

After three more rounds of brain teasers, Facebook will fly the top 25 coders to its head office in Menlo Park, for an adrenaline-soaked finale this March that will award the champion \$5,000. In return, Facebook gets a shot at hiring the stars discovered along the way.

"I'm in an all-out land grab for talent," says Jocelyn Goldfein, Facebook's director of engineering and the most senior woman on its technical staff. The social network builds almost all of its own software, and young, smart coders are the company's most critical asset as it manages the comments, photos, and "likes" of more than 800 million users. "We are in uncharted waters every day," says Goldfein. "What's great about young people is that they don't know what's impossible, so they try crazy things and lead us to be the first to make them work."

Google and many other companies are chasing the same code slingers as Facebook, causing salaries to shoot up. Aver-

age salaries for technology professionals in Silicon Valley rose 5.2 percent in 2011 to break the \$100,000 barrier, while nationally pay rose just 2 percent, according to a recent salary survey. One graduating college senior, in an anonymous posting on the Web, claimed that Facebook offered a \$100,000 salary, a \$50,000 signing bonus, and \$120,000 in stock options. Facebook declined to comment.

According to the prospectus filed in connection with Facebook's planned initial public offering of stock, the company's head count jumped from 2,127 to 3,200 full-time employees in 2011. Unlike some large companies, Facebook does not leave recruiting programmers to its human resources department. "The HR departments are in one building and engineering is in another," says Goldfein. "Recruitment sits with us."

The best hiring strategies simultaneously test skills and advertise Facebook's internal culture, which Goldfein says values "clever workarounds that shortcut complexity." In

addition to the Hacker Cup and a series of similar "Camp Hackathon" contests that tour U.S. colleges, there's a set of fiendishly tricky puzzles that Facebook maintains online. Solving them with sufficient style can net a phone call from a recruiter. "This is a way to say that if you're brilliant we don't care where you worked and if you have a college degree," says Goldfein.

All of that reinforces Facebook's status as a cool place to work. On Glassdoor, a job information site, Facebook leads technology companies in a ranking by employees of the best workplaces. In another survey that asked workers under 40 where they would most like to get a job, Facebook placed third, behind Google and Apple. Increasingly, other large technology companies aren't even the stiffest competition for talent, says Rusty Rueff, a board member at Glassdoor. Many talented young people in Silicon Valley are finding that investors and startup accelerator programs will back them to go it alone and found their own companies.

One consequence is that technology companies are buying startups simply as a way to hire their twentysomething founders. Another is that companies aren't hiring for specific jobs. Facebook puts new hires through a six-week boot camp where they rotate through projects, choosing the one that suits them best. "Facebook and other companies doing this are saying, 'You can work for us and still be entrepreneurial and create your own thing,'" Rueff says.

Although the coder competition looks like a fun and freewheeling meritocracy, it also reflects problems in the U.S. education system. Very few women participate, and most of the winners are from overseas. "Facebook [is] aggressively going to other countries because there aren't enough skilled people in the U.S.," says Goldfein.

Of the 2011 Hacker Cup winners, all three were foreign men 26 or younger. Facebook hired the second-place finisher. The first-place winner was already employed by Google. **B**

More on the Youth Effect

Read the complete report at technologyreview.com/business

Additional stories include:

Q&A with Aaron Swartz

A digital guerrilla explains why business should embrace Internet freedom.

A Very Young CEO

The world is a game, so how do I win?

Mentor Shortage

Too many startups and too few experienced entrepreneurs spells trouble.

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ART

Through a Camera, Darkly

The technology of lenses has made art richer and more meaningful for hundreds of years. A Gerhard Richter retrospective shows Germany's most famous artist responding to the camera over a lifetime of painting.

By MARTIN GAYFORD

Around 1670, Johannes Vermeer of Delft painted a young woman making lace. She can be seen concentrating intently on what she is doing. In the foreground is a sewing cushion, a piece of needlework equipment consisting of a box with a padded textile cover, from which skeins of red and white thread are spilling out onto another surface. Loose, liquid, those fibers resemble to a contemporary eye something of which Vermeer could have had no conception: abstract art. When you look at that lovely festoon of red looping over the blue table cover, Jackson Pollock comes irresistibly to mind.

Last autumn this beautiful, tiny painting (it is slightly more than eight by nine inches) was the centerpiece of a beguiling exhibition at the Fitzwilliam Museum in Cambridge, England ("Vermeer's Women: Secrets and Silence"). I am going to concentrate on a single observation about *The Lacemaker*: Vermeer must have looked at the model and her surroundings through a lens.

There has always been some academic resistance to this line of thought about Vermeer (perhaps because we want our greatest painters to be supremely skilled draftsmen who do not require any mechanical aid). But even the scholarly authors of the catalogue for the definitive Vermeer exhibition (held in Washington and The Hague in 1995–96) concluded, "The optical effect of the threads certainly derives from a camera obscura image."

What one sees in *The Lacemaker* is a great painter making brilliant use of the distortions a lens can cause. The picture is constructed in terms of differing fields of focus. The foreground is fuzzy, but the area in which the woman

is absorbed—her fingers, the bobbins, the lace—is absolutely sharp. Her head and shoulders are, again, gently blurred. Vermeer was making art—creatively and innovatively—out of the visual anomalies created by a piece of antique technology, the filmless camera.

Gerhard Richter:
Panorama
Tate Modern, London
October 2011
to January 2012
Neue Nationalgalerie,
Berlin
February to May 2012
Pompidou Center, Paris
June to September 2012

Vermeer's Women:
Secrets and Silence
Fitzwilliam Museum,
University of Cambridge
October 2011
to January 2012

Damien Hirst's
spot paintings
Gagosian Gallery locations
worldwide

Fast-forward 340-odd years to the Tate Modern, in London, where a magnificent retrospective exhibition of the work of Gerhard Richter, titled "Panorama," pulled large crowds from October to January. (The exhibition is now at the Nationalgalerie in Berlin and will move to the Pompidou Center in Paris.) During the interval between Vermeer and Richter, the camera obscura evolved into the photographic camera, and the photograph became the dominant visual form of our culture.

"Panorama" makes it clear that Richter is among the truly outstanding painters of the





last half-century. And going from *The Lacemaker* to the Richter exhibition revealed to what an extent Richter has worked—like Vermeer in that picture—by using not just the photographic image but also the blurring, smudging, and hazing a lens can create.

Indeed, Richter has said that he wants to paint like Vermeer, whom he has called “the artist-god.” His own works are “a little damaged,” he told the curator Robert Storr, and he means it literally: he was so frustrated by his inability to measure up to Vermeer that he attacked some paintings with a palette knife. “I really want to make beautiful

paintings,” he said. “I couldn’t quite hold it; they’re not as beautiful as Vermeer.”

On occasion, he has consciously echoed the Dutch master. Richter’s 1994 painting *Reader* (*Lesende*) is an updated version of Vermeer’s *Woman in Blue Reading a Letter* (c. 1663–64). But there’s much more to the relationship than such occasional visual quotations. As you walk through “Panorama,” you realize that Richter has been endlessly fascinated by the interplay between the sharp, clear image and the visual noise created by the lens—just like Vermeer in *The Lacemaker*.

Gerhard Richter’s *Reader*.

PHOTOGRAPHIC MEMORY

Many of Richter’s most characteristic works depend on the way the camera—if it doesn’t quite lie—tends to be “economical with the truth” (as a British civil servant, in the witness box, once described the deliberate lacunae that give a “misleading impression”). Some of the best-known were derived from black-and-white photos, in some cases family snapshots. In the 1965 work *Uncle Rudi* (*Onkel Rudi*), the subject stands smiling, wearing a German officer’s uniform from



the Nazi era; in *Aunt Marianne* (*Tante Marianne*), also from 1965, his aunt holds an infant who seems about to burst into tears.

At first glance, these might seem chilly. Almost all of them are distorted, as if the camera was moving at the moment the shutter clicked; most have zones of out-of-focus fog. But the chill is an illusion, and the blur (achieved by brushing the not-quite-dry paintings with a soft brush) a highly conscious device. When I talked to Richter in 2008, I suggested that the latter was a way of adding distance and detachment to the picture. He denied it: “That’s not what I think about my pictures. I feel they are shameless, they so directly reflect what I am thinking and feeling. I’m not really a cool artist.”



At left, *The Lacemaker*, by Johannes Vermeer, and a close-up of the threads the subject is using. Above, Richter's *Aunt Marianne*.

Blurring was there in the original photographs, but it was exaggerated in the paintings for several reasons. One motive was to make it possible to look at the unbearable. Richter’s aunt suffered from mental problems and was forcibly sterilized and then murdered in a Nazi euthanasia program. The child in her portrait is the artist himself.

In a series of 15 photo-paintings Richter did in 1988 about the careers and deaths of the Baader-Meinhof terrorist group, the darker the subject matter, the more it is veiled in fuzz and smear. In *Hanged* (*Erhängte*), the body of Gudrun Ensslin suspended in her cell seems to be seen through a thick mist; *Arrest 1* and *Arrest 2* (*Festnahme 1* and *Festnahme 2*), showing Holger Meins being forced to strip naked, are barely legible at all, just masses of sinister gray patches.

The effect of the blur, then, is emotional but also makes a Germanic philosophical point. “Lack of focus is important for me,” Richter once said, “because I cannot see it exactly anyway and do not know it”—“it” being what he is painting. In other words, an image is always partial and maybe misleading. You never really see what Kant called the “thing-in-itself.”

The smear and blurring are also beautiful. They help give the pictures presence

as works of art, making them what Richter calls “*ansehnlich*”—meaning considerable, or worth seeing. In the late 1960s and early 1970s he painted a series based on aerial photographs of cities. One, *Townscape Paris* (*Stadtbild Paris*), completed in 1968, was painted in a deliberately loose, free fashion and looks like an abstract work up close. Only at a distance does it resolve into buildings and streets, suggestive of the bombed-out ruins that characterized most German towns in 1945. It is not quite clear that Richter intended that last layer of meaning, though he noticed it later. “My paintings,” he has said, “are smarter than I am.”

RANDOM BEAUTY

Richter’s work generates its own beauties and meanings. A subgenre of his abstract oeuvre is derived in a systematic, mathematical way from color charts. To create the 1974 work *4096 Colors* (*4096 Farben*), he took the primary colors red, yellow, and blue, plus green, mixed 1,024 shades from them, and put those down four times each in neat squares. The energy, even euphoria, of the result is not a feeling expressed by the artist but an automatic effect. Damien Hirst’s spot paintings are generated by a similar system. These works, currently on

exhibit in Gagosian Gallery locations worldwide, follow the simple rule that no color is repeated in a single picture. The appearance of the result is dictated by the size of the dots and of the canvas. Hirst's titles are all the names of pharmaceutical products, implying that actual human emotions are chemical in origin, just as the joy of the pictures is created by artifice.

But Richter's abstract pictures have much more often been loose and what art historians call "painterly." Some have been made with the aid of a squeegee, a tool for smearing, which is pulled over the work again and again, unpeeling some sections of paint and smudging others. This, too, is a process open to chance. Richter describes it as a succession of yes/no decisions, a process of accepting or rejecting what has happened until the artist is satisfied by the result. Other than that, he is not entirely in control. The paintings can suggest a glimpse of sunlight filtered through leaves, or reflections on water.

Richter has published a monumental album of his photographic sources, entitled *Atlas*, and he has made whole books of photographs, such as *Wald* (2008), a little masterpiece consisting of shots of a wood near Cologne. The latter is, like so much of his work, about how randomness—in this case a dense tangle of trunks and twigs—can generate beauty and a sort of order. But even such important works as *Wald* and *Atlas* are ancillary to his painting.

"I make a lot of photographs," Richter told me, "but I am not very interested in photography as an art. They don't touch me that much." What affects him most, perhaps, is the Vermeer effect: the interaction between the cool, apparently objective image created by a piece of equipment—a camera—and the free play of paint. **tr**

MARTIN GAYFORD IS CHIEF ART CRITIC FOR BLOOMBERG NEWS. HE REVIEWED DAVID HOCKNEY'S NEW VIDEO INSTALLATIONS IN THE SEPTEMBER/OCTOBER 2011 ISSUE OF *TECHNOLOGY REVIEW*.

COMPUTING

Turing's Enduring Importance

The path computing has taken wasn't inevitable. Even today's machines rely on a seminal insight from the scientist who cracked Nazi Germany's codes.

By SIMSON L. GARFINKEL

When Alan Turing was born 100 years ago, on June 23, 1912, a computer was not a thing—it was a person. Computers, most of whom were women, were hired to perform repetitive calculations for hours on end. The practice dated back to the 1750s, when Alexis-Claude Clairaut recruited two fellow astronomers to help him plot the orbit of Halley's comet. Clairaut's approach was to slice time into segments and, using Newton's laws, calculate the changes to the comet's position as it passed Jupiter and Saturn. The team worked for five months, repeating the process again and again as they slowly plotted the course of the celestial bodies.

Today we call this process dynamic simulation; Clairaut's contemporaries called it an abomination. They desired a science of fundamental laws and beautiful equations, not tables and tables of numbers. Still, his team made a close prediction of the perihelion of Halley's comet. Over the following century and a half, computational methods came to dominate astronomy and engineering.

By the time Turing entered King's College in 1931, human computers had been employed for a wide variety of purposes—and often they were assisted by calculating machines. Punch cards were used to control looms and tabulate the results of the American census. Telephone calls were switched using numbers dialed on a ring and interpreted by series of 10-step relays. Cash registers were ubiquitous. A "millionaire" was not just a very rich person—it was also a mechanical calculator that could multiply and divide with astonishing speed.

All these machines were fundamentally limited. They weren't just slower, less reliable, and dramatically poorer in memory than today's computers. Crucially, the calculating and switching machines of the 1930s—and those that would be introduced for many years to come—were each built for a specific purpose. Some of the machines could perform manipulations with math,



MACHINE LEARNING Even before digital computers existed, Turing described the fundamental mathematical principles that would govern them.

some could even follow a changeable sequence of instructions, but each machine had a finite repertoire of useful operations. The machines were not general-purpose. They were not *programmable*.

Meanwhile, mathematics was in trouble.

In the early 1920s the great German mathematician David Hilbert had proposed formalizing all of mathematics in

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terms of a small number of axioms and a set of consistent proofs. Hilbert envisioned a technique that could be used to validate arbitrary mathematical statements—to take a statement such as “ $x + y = 3$ and $x - y = 3$ ” and determine whether it was true or false. This technique wouldn’t rely on insight or inspiration on the part of the mathematician; it had to be repeatable, teachable, and straightforward enough to be followed by a computer (in Hilbert’s sense of the word). Such a statement-proving system would be powerful stuff indeed, for many aspects of the physical world can readily be described as a set of equations. If one were able to apply a repeatable procedure to find out whether a mathematical statement was true or false, then fundamental truths about physics, chemistry, biology—even human society—would be discoverable not through experiments in the lab but by mathematicians at a blackboard.

But in 1931, an Austrian logician named Kurt Gödel presented his devastating incompleteness theorem. It showed that for any useful system of mathematics, it is possible to create statements that are true but cannot be proved. Then came Turing, who drove the final stake through Hilbert’s project—and in so doing, set the path for the future of computing.

As Turing showed, the issue is not just that some mathematical statements are unprovable; in fact, no method can be devised that can determine in all cases whether a given statement is provable or not. That is, any statement on the blackboard might be true, might be false, might be unprovable ... and it is frequently impossible to determine which. Math was fundamentally limited—not by the human mind but by the nature of math itself.

The brilliant, astonishing thing was the way Turing went about his proof. He invented a logical formalism that described how a human computer, taught to follow

a complex set of mathematical operations, would actually carry them out. Turing didn’t understand how human memory worked, so he modeled it as a long tape that could move back and forth and on which symbols could be written, erased, and read. He didn’t know how human learning worked, so he modeled it as a set of rules that the human would follow depending on the symbol currently before her and some kind of internal “state of mind.” Turing described the process in such exact detail that ultimately, a human computer wasn’t even needed to execute it—a machine could do it instead.

Turing called this theoretical entity the “automatic machine” or a-machine; today we call it a Turing machine.

In a 1936 paper, Turing proved that the a-machine could solve any computing problem capable of being described as a sequence of mathematical steps. What’s more, he showed that one a-machine could simulate another a-machine. What

gave the a-machine this power was that its tape could store both data and instructions. In the words of science historian George Dyson, the tape held both “numbers that *mean* things” and “numbers that *do* things.”

Turing’s work was transformative. It made clear to the designers of early electronic computers that calculating machines didn’t need a huge inventory of fancy instructions or operations—all they needed were a few registers that were always available (the “state of mind”) and a memory store that could hold both data and code. The designers could proceed in the mathematical certainty that the machines they were building would be capable of solving any problem the humans could program.

These insights provided the mathematical formulation for today’s digital computers, though it was John von Neumann who took up Turing’s ideas and is credited with the machines’ design. Von Neumann’s design had a central core that fetched both

**Turing’s Cathedral:
The Origins of the
Digital Universe**
George Dyson
Pantheon Books, 2012

**When Computers
Were Human**
David Alan Grier
Princeton University
Press, 2005

**Alan Turing:
The Enigma**
Andrew Hodges
Simon & Schuster, 1983

instructions and data from memory, performed mathematical operations, stored the results, and then repeated. The machine could also query the contents of multiple locations in memory as necessary. What we now call the von Neumann architecture is at the heart of every microprocessor and mainframe on the planet. It is dramatically more efficient than the a-machine, but mathematically, it's the same.

Incidentally, this essential feature of computers helps explain why cybersecurity is one of the most troubling problems of the modern age. For one thing, Turing showed that all a-machines are equivalent to one another, which is what makes it possible for an attacker to take over a target computer and make it run a program of the attacker's choosing. Also, because it's not always possible to discern what can be proved, a Turing machine cannot—no matter how much memory, speed, or time

it has—evaluate another Turing machine's design and reliably determine whether or not the second machine, upon being given some input, will ever finish its computations. This makes perfect virus detection impossible. It's impossible for a program to evaluate a previously unseen piece of software and determine whether it is malicious without actually running it. The program might be benign. Or it may run for years before it wipes the user's files. There is no way to know for sure without running the program.

In 1938 Turing began working with the British government and ultimately helped design a series of machines to crack the codes used by the Germans in World War II. The best source for that story is Andrew Hodges's biography *Alan Turing: The Enigma*. Unfortunately, some details about Turing's wartime work were not declassified until 2000, 17 years after Hodges's book

(and nearly 50 years after Turing committed suicide). As a result, his full contributions have not been well told.

Many histories of computing give the impression that it was a straightforward set of engineering decisions to use punch cards, then relays, then tubes, and finally transistors to build computing machines. But it wasn't. General-purpose machines required Turing's fundamental insight that data and code can be represented the same way. And keep in mind that all of today's computers were developed with the help of slower computers, which in turn were designed with slower computers still. If Turing had not made his discovery when he did, the computer revolution might have been delayed by decades. **tr**

TR CONTRIBUTING EDITOR SIMSON L. GARFINKEL IS AN ASSOCIATE PROFESSOR OF COMPUTER SCIENCE AT THE NAVAL POSTGRADUATE SCHOOL. HIS VIEWS DO NOT REPRESENT THE OFFICIAL POLICY OF THE UNITED STATES GOVERNMENT OR THE DEPARTMENT OF DEFENSE.

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ADVANCING SCIENCE, SERVING SOCIETY

Rolling, Rolling, Rolling ...

A toy ball moves under the command of a smart-phone application.

By STEPHEN CASS

MUCH OF THE FUN of the Sphero toy comes from its mysterious nature: it has no buttons, no battery cover, no socket for a charger. Shake it and the globe glows with colored light. Put it on the floor, call up its control application on a smart phone, and the Sphero springs to life, trundling around at the direction of an on-screen virtual joystick. The \$130 Sphero is made by Orbotix, a company that Ian Bernstein and Adam Wilson originally founded to sell Bluetooth-based control technology to manufacturers of other devices. But Bernstein and Wilson were advised that the best advertisement for their technology would be a product; a consequent late-night brainstorming session spawned the Sphero.



A CHARGING DOCK

The ball rests in a dock that uses an induction system to transfer electricity to the Sphero's two lithium-polymer batteries. A complete charge takes about three hours and provides 75 minutes of continuous driving time.

B WHEELS

Two independently controlled rubber-rimmed wheels inside the Sphero steer and drive the ball at up to 1.2 meters per second.

C TOP SLIP BEARING

Because the internal mechanism can move freely inside the plastic case, this bearing braces the mechanism when necessary, in order to keep the Sphero's wheels in firm contact with the shell.

D PRINTED CIRCUIT BOARD

A processor combines data from a three-axis accelerometer and a gyroscope to produce the precise measurements of the Sphero's roll, pitch, and yaw. These measurements are required to respond correctly to commands radioed by a smart phone over a Bluetooth connection.

E BLUETOOTH RADIO AND ANTENNA

This system, with a maximum range of over 50 meters in optimum conditions, is used to communicate with mobile devices. Developers can download a software development kit from Orbotix and write their own iOS or Android control applications for the Sphero.

F MULTICOLOR LED

The light from a single LED package with red, green, and blue elements is diffused by the translucent casing to make the Sphero glow. Different colors signal information such as whether the device is charging or when the motor speed is being temporarily boosted. The user can select the colors by way of the smart-phone application.



www

See a video of the Sphero in action:
technologyreview.com/hack

demo



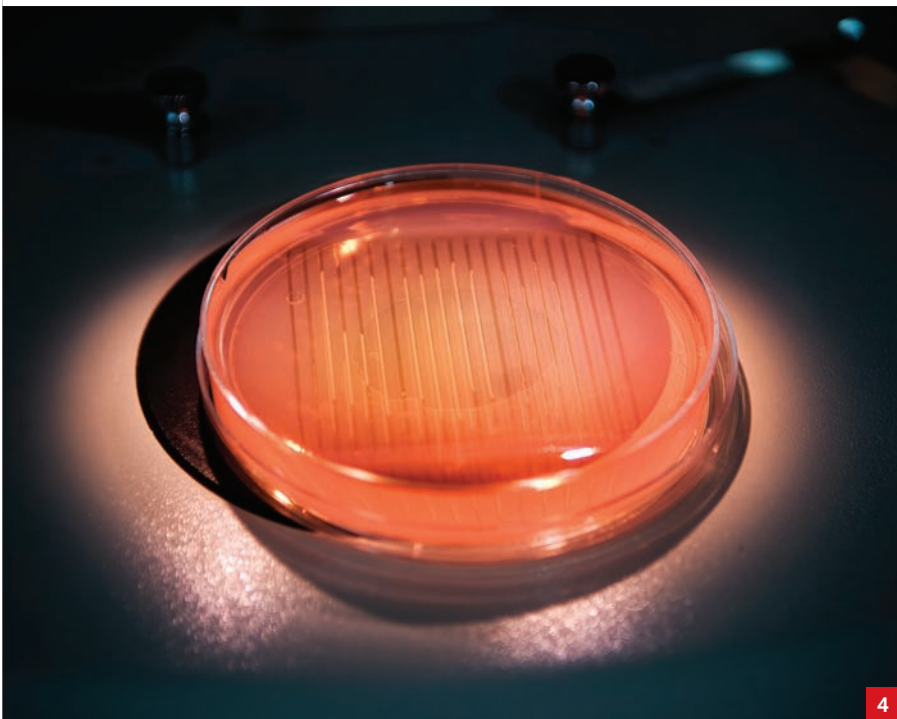
Printing Muscle

Organovo's 3-D printer creates human tissues that could help speed drug discovery.

By LAUREN GRAVITZ

In a small clean room tucked into the back of San Diego-based startup Organovo, Chirag Khatiwala is building a thin layer of human skeletal muscle. He inserts a cartridge of specially prepared muscle cells into a 3-D printer, which then deposits them in uniform, closely spaced lines in a petri dish. This arrangement allows the cells to grow and interact until they form working muscle tissue that is nearly indistinguishable from something removed from a human subject.

The technology could fill a critical need. Many potential drugs that seem promising when tested in cell cultures or animals fail in clinical trials because cultures and animals are very different from



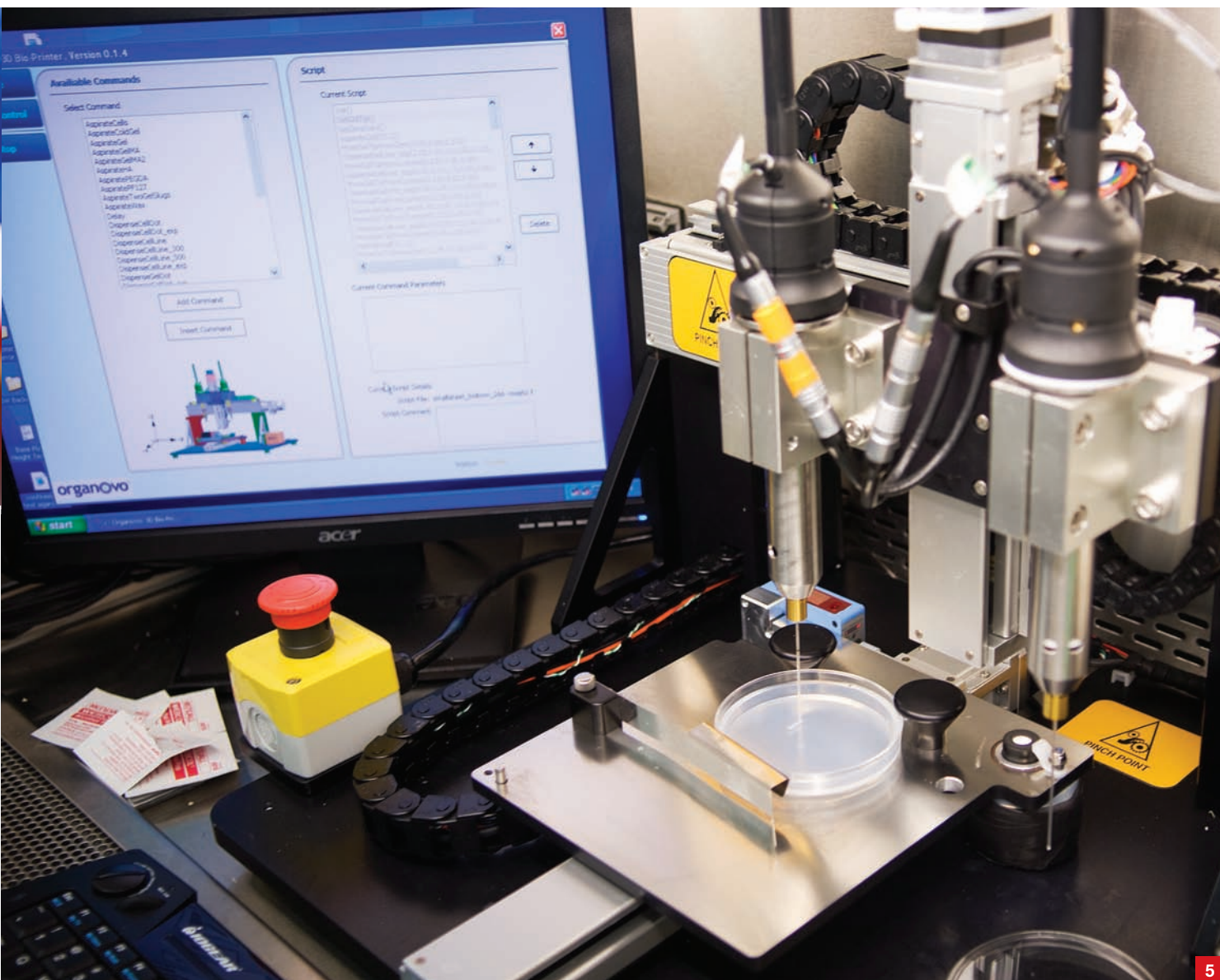
human tissue. Because Organovo's product is so similar to human tissue, it could help researchers identify drugs that will

fail long before they reach clinical trials, potentially saving drug companies billions of dollars. So far, Organovo has built tissue of several types, including cardiac muscle, lung, and blood vessels.

Unlike some experimental approaches that have used ink-jet printers to deposit

cells, Organovo's technology enables cells to interact with each other much the way they do in the body. They are packed tightly together and incubated, prompting them to adhere to each other and trade chemical signals. When they're printed, the cells are kept bunched together in a paste that helps them grow, migrate, and align themselves properly. Muscle cells, for example, orient themselves in the same direction to create tissue that can contract.

FRANK ROGOZIENSKI/WONDERFUL MACHINE



So far, Organovo has made only small pieces of tissue, but its ultimate goal is to use its 3-D printer to make complete organs for transplants. Because the organs would be printed from a patient's own cells, there would be less danger of rejection.

Organovo plans to fund its organ-printing research with revenue from printing tissues to aid in drug development. The company is undertaking experiments to prove that its technology can help researchers detect drug toxicity earlier than is possible with other tests, and it is setting up partnerships with major companies, starting with the drug giant Pfizer. [tr](#)

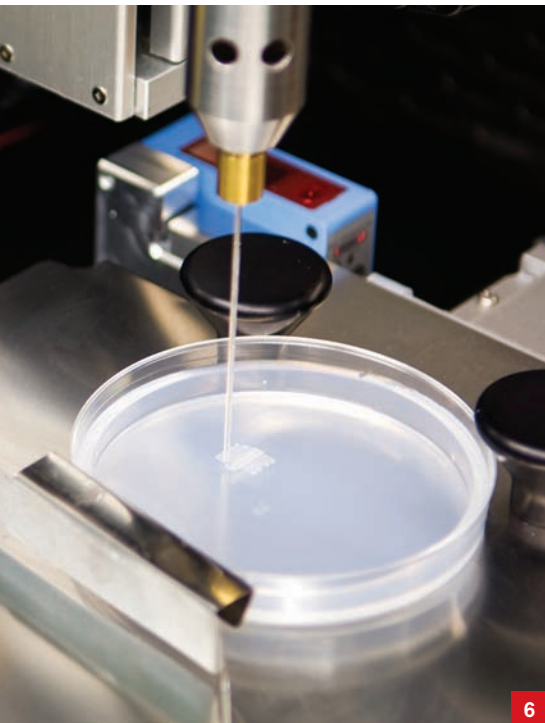
1. To create the ink that Organovo uses to print tissue, senior scientist Chirag Khatiwala first grows cells in culture.

2. Once the researchers have enough cells, they apply an enzyme that frees them from the growing surface and then use a centrifuge to pack them into a small, dense pellet like the one seen at the bottom of this vial, which holds skeletal muscle cells.

3. The pellet is sucked up into small glass capillary tubes, which are then incubated in growth medium. During this incubation period, the cells begin to adhere to each other.

4. Once the cells can hold together as a unit, researchers push them out of the capillary tubes and into a petri dish, where they are submerged in a nutrient broth. The cells feed and continue to interact with each other, sending and receiving chemical signals and forming the beginning stages of solid tissue.

5. After this period of incubation, the cells are sucked back up into glass capillary tubes that serve as ink cartridges. These are loaded into the printer at right, which has been programmed with the script shown on the computer screen to define the shape that will be deposited.



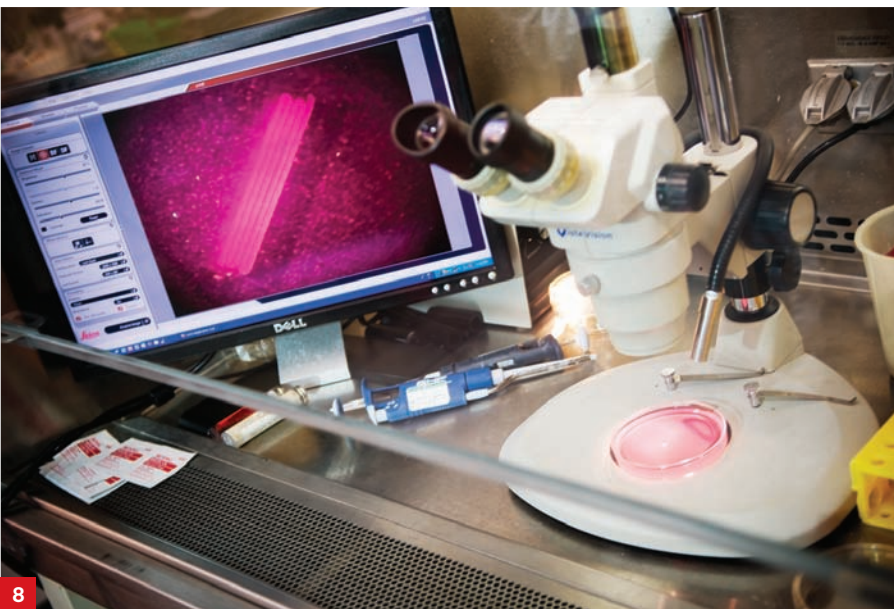
6

6. The printer deposits ink one line at a time on top of a layer of inert gel.

7. The cells form a rectangle 8 millimeters long by 1.5 millimeters wide. The rectangle can be seen in the center of the back-and-forth pattern shown here. That pattern is made of inert gel that holds the tissue in place so that it won't float away when nutrient medium is added to the dish.

7

8. The printed tissue is shown magnified with a microscope and displayed on a computer monitor. Over the next few days, the distinct rows visible here will disappear as the cells divide, communicate, organize, and merge into a single piece of muscle tissue. The muscle tissue is printed in one pass, since a single layer of it is optimal for drug testing, but the printer is just as adept at building multilayered tissue such as functional blood vessels.



8

FRANK ROGOWSKI/WONDERFUL MACHINE



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BIOMEDICINE

Obesity Fighter

A newly discovered hormone mimics the effects of exercise

SOURCE: "A PGC1- α DEPENDENT MYOKINE THAT DRIVES BROWN-FAT-LIKE DEVELOPMENT OF WHITE FAT AND THERMOGENESIS"

Bruce Spiegelman et al.
Nature 481: 463–468

RESULTS: Researchers discovered a hormone that is produced when both mice and humans exercise. Increasing the levels of the hormone in mice resulted in some of the same benefits as exercise. It caused white fat, which stores energy, to turn into brown fat, which burns stored energy to generate heat. Mice that were given the hormone lost weight and showed a decrease in diet-induced insulin resistance, which is connected to diabetes.

WHY IT MATTERS: The hormone may prove useful for treating diabetes and obesity. The discovery also sheds light on how exercise changes

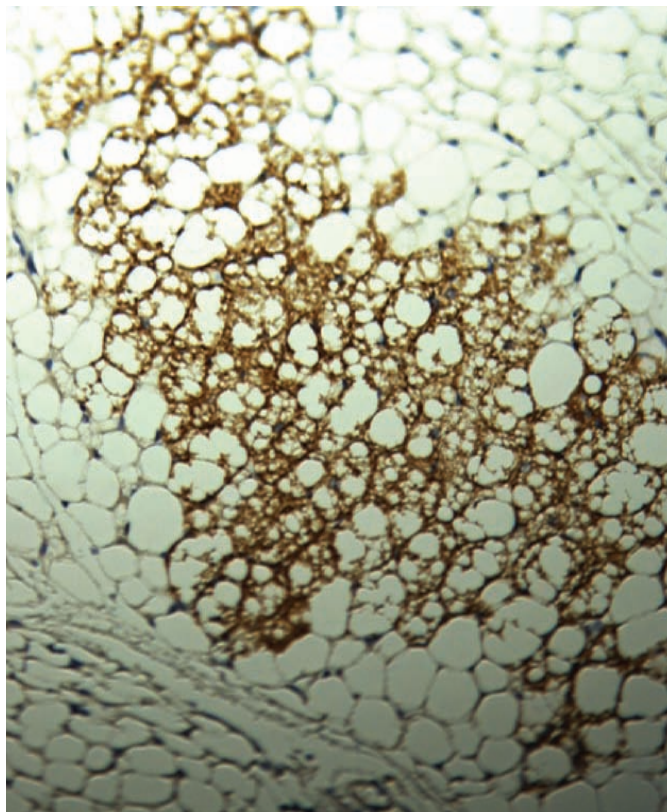
ANTI-OBESITY FAT Mice that were genetically altered to produce the hormone irisin have more brown fat, shown here.

the way the body responds to sugar and utilizes fat.

METHODS: Earlier research had shown that the protein PGC1- α is involved in regulating the expression of other proteins and is connected with exercise. The researchers identified five proteins controlled by PGC1- α . They discovered that one of these, FNDC5, is connected to the browning of

fat cells and that FNDC5, in turn, is modified in cells and secreted as a hormone, which the researchers named irisin. They put mice and humans on a multiweek exercise regimen, after which they measured increased levels of irisin in both. They fed mice a diet high in fat to make them obese and insulin resistant. Then they introduced a gene into these mice that increased their production of the hormone. They measured the physical changes that resulted.

NEXT STEPS: Ember Therapeutics, a company that the researchers founded before undertaking the study, is looking for ways to deliver the hormone therapeutically.



Muscle Enhancer

Changing proteins expressed in muscle allows mice to run farther

SOURCE: "NCOR1 IS A CONSERVED PHYSIOLOGICAL MODULATOR OF MUSCLE MASS FUNCTION AND OXIDATIVE FUNCTION"

Johan Auwerx et al.
Cell 147: 827–839

RESULTS: By modifying proteins in muscle tissue, researchers increased muscle mass in mice and triggered other changes that improved the muscles' ability to use oxygen. This allowed the mice to run longer: 80 minutes before they were exhausted, versus 60 minutes for control mice.

WHY IT MATTERS: The finding could lead to treatments for muscular dystrophy and age-related muscle loss.

METHODS: Researchers genetically engineered mice lacking in a protein, NCoR1, that works as something like a dimmer switch for other molecules in a cell, slowing the production of transcription factors that regulate the expression of genes. The protein seems to have different effects in different tissues. The researchers used a method that blocked the production of the protein only in muscle tissue and then measured changes in that tissue and in the animals' behavior.

NEXT STEPS: The researchers are searching for drugs that can selectively modulate the levels of NCoR1.

PONTUS BOSTROM

Bouncing Data

Ricocheting radio signals off the ceiling could improve the performance of data centers

SOURCE: "3D BEAMFORMING FOR WIRELESS DATA CENTERS"

Weile Zhang et al.
Proceedings of 10th ACM Workshop on Hot Topics in Networks, Cambridge, MA, November 14–15, 2011

RESULTS: Simulations by researchers at the University of California, Santa Barbara, show that using wireless signals rather than cables to link the computers inside data centers can boost the speed at which data moves inside such facilities by 30 percent. That's because the wireless links enable servers to communicate directly instead of sharing congested network cabling with all computers in the data center.

WHY IT MATTERS:

Keeping information moving more reliably within data centers could lower costs and improve performance for many services, from Facebook to financial trading platforms. Today spikes in demand can cause congestion and slowdowns because cable networks are limited by their complexity and by physical space. Wireless links could be rapidly switched on as needed to link any two points and fight data congestion.

METHODS: In the researchers' design, servers

use wireless transmitters to send tight beams that can be picked up only by the antennas on the servers at which they're aimed. To deliver those beams across a crowded server room, the researchers decided to send them over the tops of the server racks by reflecting them off metal plates on the ceiling. Radio-absorbent material around the receiving antennas limits unwanted reflections that might interfere with the wireless links. The system uses the familiar Wi-Fi protocol for sending wireless data, but at a much higher frequency than that used in homes and businesses (60 gigahertz rather than 2.4 gigahertz). The higher-frequency signal allows data to be transferred at a much greater rate.

NEXT STEPS: The researchers are now outfitting a small data center with the wireless technology.

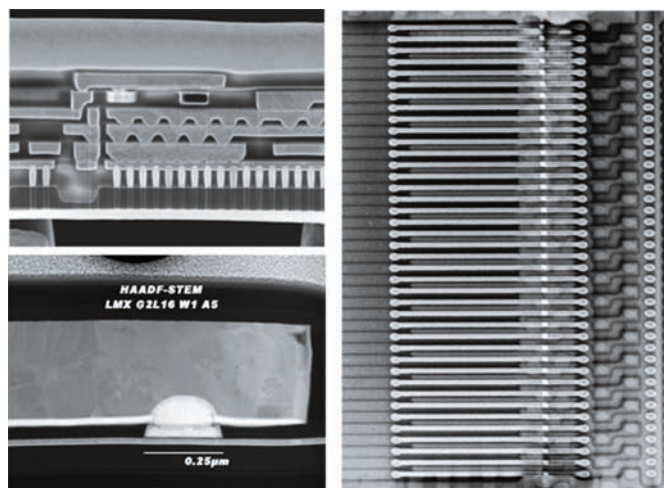
Memory Milestone

An experimental form of data storage can now be made cheaply using conventional manufacturing methods

SOURCE: "RACETRACK MEMORY CELL ARRAY WITH INTEGRATED MAGNETIC TUNNEL JUNCTION READOUT"

Anthony J. Annunziata et al.
Proceedings of the IEEE International Electron Devices Meeting, Washington, D.C., December 5–7, 2011

RESULTS: Researchers at IBM made a novel type of



NANO MEMORY Nanowires, at right, are a key component of a new memory device shown in these three views.

memory, known as racetrack memory, by means of inexpensive manufacturing processes used to make conventional computer chips.

WHY IT MATTERS:

The basic design of racetrack memory, which stores information on nanowires, was first proved feasible in 2009. The technology has the potential to store data faster than hard disk drives and to store thousands of times more data in a given space (*see TR10, March/April 2009*). The early prototypes, however, were made using specialized lab processes that are impractical for mass production. By making a prototype using existing industrial processes, the researchers have shown that the technology could be commercially viable.

METHODS: The researchers used conventional lithography techniques to create the nanowires that are the basis

of racetrack memory and to attach devices needed to read out data inside. A layer of conventional silicon circuits underneath is used to operate the completed memory. The team experimented with making nanowires of different shapes and sizes to find structures that could be manufactured reliably.

NEXT STEPS: Although the prototype worked, testing showed that the magnetic properties of the nickel-iron alloy used to make the nanowires limited the amount of data each wire could store. The nickel-iron alloy was initially chosen because it is a soft magnetic material—a material with properties that make it easy to magnetize and demagnetize with an external field. The researchers are now investigating so-called hard magnetic materials, which are not easily demagnetized and could store more data.

MATERIALS

Smudge-Free Surfaces

A coating based on candle soot sheds oil and water

SOURCE: "CANDLE SOOT AS A TEMPLATE FOR A TRANSPARENT ROBUST SUPERAMPHIPHOBIC COATING"
Doris Vollmer et al.
Science 335: 67–70

RESULTS: A coating made of soot and silica repels both oil and water from glass and metal surfaces.

WHY IT MATTERS: Eyeglasses, smart phones, medical devices, and the insides of gas turbines can all benefit from coatings that keep oil

and other liquids from sticking to them. Researchers know what sorts of microscopic structures on a surface will repel oil, but the techniques used to make them have typically been too expensive for widespread commercial application. The new technique could prove much cheaper: it uses particles of soot as a template for the structures, so they don't have to be carved using a process such as photolithography.

METHODS: The researchers held a glass slide over a candle flame to coat it with soot made of nanoscale spheres that stack up, resulting in a texture that repels oil. They covered the soot with a layer of silica to keep it from washing away. Then they baked the

slide at 600 °C, which rendered the soot transparent.

NEXT STEPS: Applying soot is cheap, but the method the researchers used for applying the silica is relatively expensive. They're testing cheaper techniques.

ENERGY

Sunlight Absorber

A nanoscale pattern could lead to more efficient solar cells

SOURCE: "BROADBAND POLARIZATION-INDEPENDENT RESONANT LIGHT ABSORPTION USING ULTRATHIN PLASMONIC SUPERABSORBERS"
Harry Atwater et al.
Nature Communications 2: 517

RESULTS: Thin films of silver ordinarily absorb only 5 percent of visible light. By applying a pattern of nanoscale

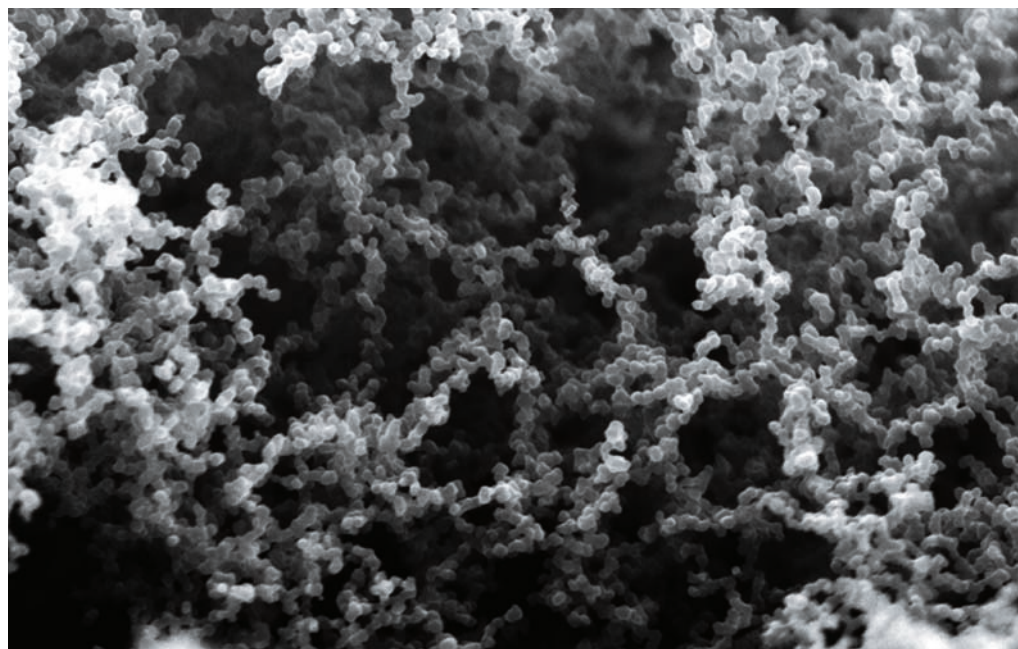
shapes to such a surface, researchers increased absorption to 70 percent. The patterned film absorbs light from the entire visible spectrum and from almost any angle.

WHY IT MATTERS: The advance could lead to solar cells that are far thinner and cheaper than conventional ones, because less semiconductor material would be needed to absorb sunlight. Researchers have known that nanoscale patterns can greatly enhance light absorption by gathering light waves the way antennas gather radio waves. But these patterns typically absorb only light of certain wavelengths, allowing most of the solar spectrum to escape. That makes them impractical for use in solar cells. The researchers have demonstrated that their patterns can be used to absorb a wide range of wavelengths, opening the door for their use in photovoltaic devices.

METHODS: The researchers used lithography to carve patterns of tiny wedge shapes placed end to end. The narrow end of the wedges can absorb short wavelengths at the blue end of the spectrum, and the wider end absorbs longer-wavelength red light.

NEXT STEPS: The researchers are working to apply the nanoscale design to materials used in solar cells. In recent, unpublished experiments, they showed that the patterns can allow thin films of silicon to absorb as much light as unpatterned silicon films 25 times as thick. **tv**

SOOT PARTICLES The microscopic structure of a layer of soot, shown here in an image from an electron microscope, provides a template for a new oil-repelling coating.



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Putting Death Out to Pasture

One writer wondered if cows' milk was the key to human longevity.

By TIMOTHY MAHER

We could be on the verge of advances that extend the human life span by decades. In 2010, for example, a Stanford team increased the life span of worms by up to 30 percent by blocking the expression of certain proteins. That same year, researchers at Boston University identified 150 places on the human genome that are responsible for long life, and Harvard researchers rejuvenated mice by manipulating the animals' telomeres, the portion of DNA that caps chromosomes.

It might seem as if a magic pill isn't so far off. But before we get too cheery about the prospects for these discoveries, it's useful to be reminded of the many longevity "breakthroughs" that have come and gone in the past. One such potential advance was hailed in the November 1929 issue of *Technology Review*, in an essay called "Fore-stalling Death: The Cow's Contribution to Human Longevity," by James A. Tobey.

None of the explorers in the realm of eternal life, none of the necromancers or alchemists of old, none of the gazers at crystals or the readers of the stars, have been successful in their quest for the fountain of youth. Modern science has done better.

In the previous 125 years, Tobey observed, average life span had risen from the low 30s to the upper 50s. This was primarily due to reductions in infectious disease and in the infant death rate—in 1929, he noted, there were a mere 64 deaths per 1,000 infants (today's rate in the United States is six deaths per 1,000). The primary causes of death were changing as well.

Tuberculosis, long the captain of the men of death, and frequently the despoiler of young manhood, has dropped to fifth place. Ahead of it are heart disease, cancer, nephritis, and cerebral hemorrhage, in that order ... Typhoid fever, for instance, now



causes a mortality only one-fifth as great as a quarter of a century ago.

This was good, but Tobey—author of more than a dozen books on public health, including *Cancer: What Everyone Should Know About It* (1932) and *Your Diet for Longer Life* (1948)—felt we could do better. It wasn't enough to simply reduce a threat such as infectious disease—it was imperative that we find something we could add to our lives, or maybe simply increase our intake of something we were already con-

suming. He felt recent research might have uncovered just such a substance.

It is a well recognized fact ... that those races which have been nourished on foods containing a preponderance of dairy products have always been the most vigorous and long-lived, as well as the most important historically. The conquerors have been users of cows.

He pointed to recent experiments at Columbia University, wherein one set of rats had been given an "adequate diet" of one-sixth dried whole milk and five-sixths whole wheat. An "optimal diet" group, meanwhile, received double the milk and less wheat.

The average duration of life was almost exactly ten percent greater in those subjects receiving the optimal diet ... Is it possible that we have had the fountain of youth within our grasp throughout the ages that man has been seeking this liquid phantasm? Milk has always been recognized as the one most nearly perfect food ... but apparently it possesses hitherto undreamed of virtues.

Those virtues appear to have dimmed 25 years later, when Tobey revisited the subject in a May 1954 *TR* piece called "Is There a Limit to Human Life?" He didn't mention dairy once in that lengthy article, and his tone in general was less upbeat, even though the average U.S. life expectancy had risen to 68 years (it is now 78).

Centenarians are, of course, always asked as to what they attribute their great ages, but invariably their answers are a bit weird, often absurd, and completely lacking in uniformity. In the olden days the few favored persons who attained to great old age undoubtedly did so through the operation of the law of the survival of the fit, but in our modern sanitary civilization the achievement of unusual old age is probably largely a matter of heredity and—luck. tr

TIMOTHY MAHER IS *TR*'S ASSISTANT MANAGING EDITOR.

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